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LONG TERM PERFORMANCE AND SAFETY OF EARTHEN HOG MANURE STORAGES

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Long-term Performance of Earthen Manure Storages in Saskatchewan

Final Report Submitted to:
Agricultural Development Fund
Saskatchewan Agriculture and Food

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Abstract

This report covers the setup and initial results of a long-term monitoring project for earthen manure storages in use at swine production facilities in Saskatchewan. The project was initiated by several swine producers and the Geotechnical Division Unit of the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada. The project received funding from the Agricultural Development Fund of Saskatchewan Agriculture and Food. Further support was given by PFRA (in-kind), Sask Pork, Big Sky Farms Inc., Genex Swine and Prairie Swine Center Elstow Research Farm.

Under this study, three (3) new two-cell storages have been instrumented with approximately 60 monitoring tips installed at each site. All storages have a minimum 600 mm thick recompacted clay liner. The system is capable of giving a water sample, hydrostatic head, temperature and ORP at each monitoring tip location. Additionally, two (2) older storages (15 to 18 years of use) were instrumented with piezometer nests on the down gradient side of the storage. Neither storage was constructed with a liner of any kind.

Supporting studies included:

- Ponding of 3 meters of effluent head over 800 mm x 300 mm diameter soil columns from two sites. Hydraulic conductivity and ORP testing of the columns as well as sectioning of the columns and analysis of ions in pore fluid and on the exchange sites.

- Earthen manure storage (EMS) sampling and characterization with depth. All samples were filtered to 0.45 μm and then analyzed to determine the transportable source chemistry.
- Extensive soil sampling and instrumentation at one of the "older" sites:
  - installation of soil gas samplers from the surface to the water table,
  - installation of ORP microelectrodes from the surface to 11 meters below grade, and
  - detailed soil sampling through the plume (0.5 meter intervals at 5 locations) and analysis for ions in solution and on soil exchange sites.

Significant findings from this study include:

1. Groundwater mounding at EMS constructed in clayey soils occurs very rapidly (almost follows filling of the EMS)
2. Source chemistry is high in bicarbonates (HCO_3^-), ammonium (NH_4^+), potassium (K^+), chloride (Cl^-) and some times sodium (Na^+).
3. These elevated levels of monovalent cations displace calcium and, to a greater extent, magnesium on the soil exchange sites. These displaced ions form a "hard water" front at the leading edge of a plume.
4. Detection of this "hard water" offers the ability for early detection of seepage plumes
5. Bicarbonate (HCO_3^-), chloride (Cl^-) and sodium (Na^+) follow standard advection dispersion transport with no note retardation.

6. Transport of ammonium (NH_4^+) and potassium (K^+) is somewhat retarded. The ability of the soil to retard ammonium and potassium appears to be depleted exponentially as the pore water concentration increases. The significance of this is that as concentration increases, retardation decreases until a level is reach where transport is unretarded advective dispersive movement.
7. The above-mentioned process produces a relatively flat concentration front of ions advancing through the soil. This front nearly resembles "plug" flow with a velocity at C/Co= 0.5 of 0.65 and 0.5 the velocity of chloride for ammonium and potassium respectively. The significant difference being that the when the ammonium front does pass the concentration will increase relatively quickly from background to very nearly the source concentration.

The main question to arise from these studies has been in regards to the fate of the ammonium and potassium that finally resides on the exchange sites of the soil surrounding an EMS. We recommend that decommissioning studies be initiated, both laboratory and field, to give regulators an indication of the proper decommissioning procedures for EMS.

Table of Contents

Description			Page
Executive Summary			1
1.0	Introduction		11
2.0	Objectives		13
3.0	Technical Report		14
	3.1	Monitoring System Design for Newly Constructed EMS	14
	3.2	Big Sky Farms Clearfield Feeder Unit	22
		3.2.1 Site Description	22
		3.2.2 Site Background	23
		3.2.3 Installation and Chronology of Events	24
		3.2.4 Hydrological Results	25
		3.2.5 Groundwater Chemistry	26
	3.3	Genex Swine – Bon Accord Nucleus Unit	27
		3.3.1 Site Description	27
		3.3.2 Background Information	27
		3.3.3 Chronology of Events	28
		3.3.4 Results	29
	3.4	Prairie Swine Center Elstow Research Farm Inc.	30
		3.4.1 Site Description	30
		3.4.2 Site Background	30
		3.4.3 Chronology of Events	31

Description			Page
3.5	Research Site No 9		33
	3.5.1	Site Description	33
	3.5.2	Site Background	33
	3.5.3	Monitoring System Installation	33
	3.5.4	Sampling Events	35
	3.5.5	Results	37
3.6	Research Site No 1		39
	3.6.1	Site Description	39
	3.6.2	Site Background	39
	3.6.3	Monitoring System Installation	39
	3.6.4	Sampling Events	41
	3.6.5	Results	42
3.7	Source Chemistry		45
3.8	Column Study		47
4.0	Summary of Results		56
5.0	Changes from Original Proposal		58
5.1	System Design		58
5.2	Number of Sites		59
5.3	Installation		60
6.0	Future Work		61
7.0	Project Developed Materials		62

List of Figures

Figure	Page
Figure 1 – Sampling tip and instrumentation bundle for installation in monitoring systems for new storages.	4
Figure 2 – Instrumentation installation locations for monitoring system in new storages	4
Figure 3.1 – Initial proposed monitoring system	14
Figure 3.2 – Monitoring system considered for an unsaturated soil condition	15
Figure 3.3 – Instrument bundle for unsaturated system	15
Figure 3.4 - Proposed instrument bundle for monitoring in saturated conditions	17
Figure 3.5 – Location of instrument bundles installed in earthen manure storages	18
Figure 3.6– Test hole layout at each location	19
Figure 3.7 – SSRI/AEP measurements of a soil liner for insitu hydraulic conductivity	19
Figure 3.8 – Drilling on side slope with cable tool rig	20
Figure 3.9 – Soil samples in brass liners in cold storage	20
Figure 3.10 – Extruding unoxidized till (left) and a sample of fractured oxidized till (right)	21
Figure 3.11 – Trench excavation and manhole installation at Clearfield Feeder Unit.	21
Figure 3.12 – Reading ORP and thermocouples using data collector and lap top computer	22
Figure 3.13- Groundwater mounding versus increased soil salinity at Clearfield Feeder Unit site	25
Figure 3.14 – Seepage detected in the fall of 2000 in Cell 1, Clearfield Feeder Unit	26

Figure	Page
Figure 3.15 – Areal view of PSC Elstow Research Farm showing location of EMS monitoring system	32
Figure 3.16 – Test Drilling at Site No. 9	34
Figure 3.17 – Cable tool rig used for sampling and test hole installation	34
Figure 3.18 – Piezometer and source sampling at Site No. 9	36
Figure 3.19– Site No 9 section showing seepage location, pressure head in the lower silt and sand deposit and the water table induced by seepage.	37
Figure 3.20 – Site No 9 water levels October 1999 to February 2000	37
Figure 3.21 - Solution chemistry in sand lens experiencing seepage at Site No 9	38
Figure 3.22 – Arial view of Research Site No. 1	41
Figure 3.23 – Water levels at Site 1 between October 1999 and February 2000.	42
Figure 3.24 - Temperature Profiles at Site No 1 mid January	43
Figure 3.25 – ORP readings at three locations at Site No 1	43
Figure 3.26 – Ion concentrations within the plume at Site No 1	44
Figure 3.27 – Eh, EC, DO, pH, and Total Solids versus depth at Site No 1	45
Figure 3.28 – Typical source chemistry (concentration in mg/L)	46
Figure 3.29 – Typical source chemistry (concentration in mole/kg H_20)	46
Figure 3.30 – Test column setup	48
Figure 3.31 – Breakthrough curves for major cations - Column No 2	49
Figure 3.32 - Change in ion concentration on soil exchange sites versus depth - Column No 1	50
Figure 3.33 - Change in ion concentration on soil exchange sites versus depth - Column No 2	51
Figure 3.34 – Pore water chemistry ion profiles in Column No 1 at the end of testing	51
Figure 3.35 – Langmuir isotherm plot for calcium	52
Figure 3.36 – Langmuir isotherm plot for magnesium	53

Figure	Page
Figure 3.37 – Langmuir isotherm plot for sodium	53
Figure 3.38 – Langmuir isotherm plot for potassium	54
Figure 3.39 – "Shackelford" analysis of Column No 2 breakthrough data	54
Figure 3.40 – Comparison of measure versus calculated transport of potassium, ammonium and chloride for Column No 1	55

Executive Summary

In August 1997 The Department of Agricultural and Bioresource Engineering (ABE Department) along with the Geotechnical Unit of the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada embarked on a program to install monitoring systems in newly constructed earthen manure storages (EMS) in Saskatchewan. The original goal was to install at least three systems in each of 3 different soil types. The ABE Department was to provide project management, staff to assemble and install the systems and staff and equipment to acquire water samples and readings over the life of the program. The PFRA agreed to provide advisory services through senior staff as well as drilling and technical services during system installations. PFRA also agreed to analyze all soil samples at their geotechnical testing laboratory in Regina, Saskatchewan. Water sample analysis would be sent to a commercial laboratory. This program was to run for four years, 1997 to 2000.

Project funding was comprised of funds from the Agricultural Development Fund (ADF) of Saskatchewan Agriculture and Food, major in-kind contribution from PFRA, and funding from Sask Pork Research Funds. While most of the major hog production companies in Saskatchewan agreed to participate, three companies had suitable sites and agreed to contribute the required funds to pay for all materials installed at their site. The three companies are: Big Sky Farms Inc. (Clearfield Feeder Unit, Kelvington, Sask.), Genex Swine (Bon Accord Nucleus Unit, Ituna, Sask.) and Prairie Swine Center (PSC Elstow Research Farm, Elstow, Sask.).

Two other objectives of the project were to install detailed monitoring at two older EMS in the province and to conduct supporting laboratory work to assist in interpretation of the field data. The project team agreed that at least two graduate student projects could be conducted in conjunction with this project. To date Mr. Steve Gibbard is completing a M.Sc. thesis (Department of Agricultural and Bioresource Engineering, December 2002) on the automated measurement of temperature and oxidation-reduction potential (ORP) for the systems installed at the new sites. Mr. Terry Fonstad is completing a Ph.D. thesis (Department of Civil

Engineering, August 2002) on determination of source chemistry, transport mechanisms, transport coefficient determination and geochemical modeling using the information from one of the older sites and a large-scale laboratory column study.

The initial system design submitted with the proposal was fashioned after several others installed in Saskatchewan and Minnesota in similar EMS. The system involved the installation of gravel subdrains (lysimeters) below the EMS soil liner with lateral drains to manholes or vertical piping to measure piezometric head and allow water sampling. This system would be relatively inexpensive and could be installed with a small backhoe and manual labor.

This system had several shortcomings. First, the installation and back filling of a trench deep enough to allow gravity drainage of the gravel beds could potentially leak more than the liner giving erroneous readings. Secondly, the gravel beds would only allow measurement at breakthrough to the beds unless several beds were "stacked" in one location. This would entail even deeper trench excavation. Third, the gathering of water in drain tubes exposed to ambient air would cause chemical transformations defeating the attempt to monitor chemical changes in the soil pore water below the EMS. Fourth, the drained gravel bed lysimeters installed below a clay rich earth liner could produce a capillary break were by the capillary suction in the clay was strong enough to resist flow into the unsaturated gravel bed. This capillary action had recently been shown to cause preferential flow in the smaller pores of the clay resulting in flow around the gravel bed lysimeter. Although the budget had been based on this system, the project team felt that installation of systems of this type would not give the required information and had the potential to give erroneous readings.

A common hypothesis at the time of the start of this project was that the EMS would produce a "bulb" of ion rich water around the EMS that would grow with time. This bulb would slowly progress into the vadose zone (unsaturated zone) until it reach the water table and began to eventually form a groundwater mound like situation around the EMS. Based on this hypothesis conceptual design of an unsaturated system was conducted. The system involved construction of a pier like structure into each cell of the EMS. All instrumentation could be

accessed from this pier. Instrumentation included suction lysimeters at various depths for soil water sampling, soil gas samplers at various depths, time domain reflectometer (TDR) probes at various depths to monitor changes in moisture and electrical conductivity (EC), thermal conductivity sensors to measure soil suction, and vertical access tubes for down hole electro-magnetic (EM) readings to monitor changes in electrical conductivity (EC).

The resulting system was relatively expensive in terms of both materials and installation time, ice could damage most of the instruments used and most of the instruments did not have the accuracy required at soil saturations above 90 to 95%.

The project team decided to review the actual site conditions at as many previous EMS sites as possible. A review of over 25 sites of EMS constructed in clayey material revealed that most sites exhibited a water table between 3 and 6 meters below grade and that the soil at the sites was normally 95% to 98% saturated. This meant that very little seepage would produce a pressure wave resulting in groundwater mounding and 100% saturated conditions. If this was the case and given the fact that any unsaturated flow prior to mounding would be insignificant, the project team again decided to redesign the monitoring system. This new system would be intended for saturated conditions and need to provide hydraulic pressure head at the installation depth, provide a water sample not affected by ambient air and indicate temperature and ORP at the sampling point. In addition to pressure head, temperature and ORP measurements, water sample alkalinity, tempertature, pH, and EC would be taken at the site during sampling. All other chemical data could be obtained from analysis at the laboratory.

The proposed system consisted of a 300-mm long 50-mm diameter screen with a pneumatic piezometer, thermocouple, ORP microelectrode and two 3.18-mm diameter tubes installed within the screen (Figure 1). Installations not in ponded areas could utilize a 19-mm standpipe rather than the pneumatic piezometer. The 19-mm standpipe would offer must faster response to pressure head changes as compared to a more common 50-mm standpipe as a 19-mm pipe is 86% smaller than a 50-mm pipe by volume.

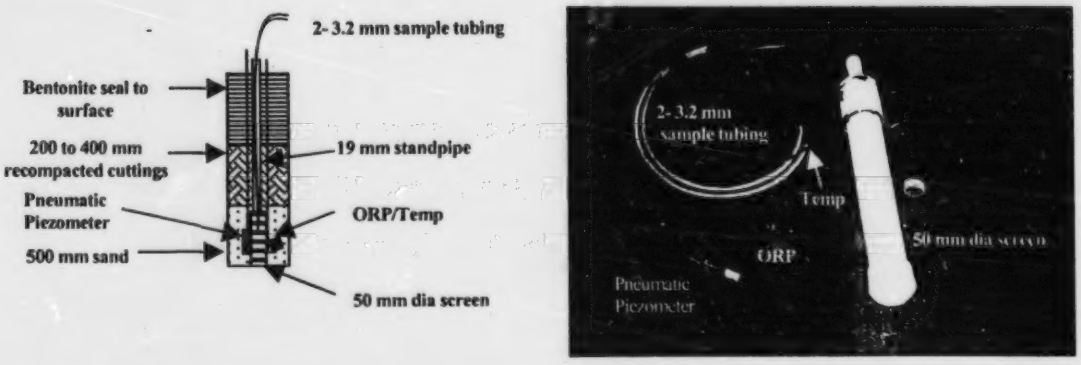

Figure 1 – Sampling tip and instrumentation bundle for installation in monitoring systems for new storages.

These standpipe piezometers would be installed at 8 depths at a location in the bottom of the storage (L1), 8 depths at a location approximately 2 meter below high water level (L2), at 4 depths at high water level (L3) and at 4 depths approximately 6 meters back of high water level (L4) (Figure 2). All installations could be accomplished with a geotechnical drilling rig and any trenching required to bring access tubes and wire from below ponded areas could be relatively shallow (<300mm deep) allowing backfilling with sealing agent. Materials costs were estimated to be between $10,000 and $15,000 per site (within the cooperator's budget). This system offered the best potential for both quality field instrument readings and representative water samples over a long period of time.

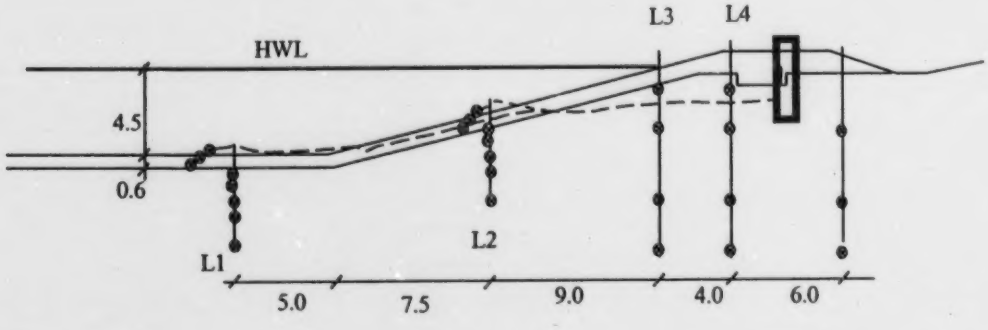

Figure 2 – Instrumentation installation locations for monitoring system in new storages

The only foreseeable problems this new system design posed was that installation would involved considerably more time and effort than the original and based on the time commitment of PFRA and the ADF funding it was anticipated that only three systems could be installed. After much discussion amongst the project team and stakeholders, it was unanimously decided that detailed information from 3 sites was preferred to the original proposal of lesser information from 9 sites.

Installation depths at locations L1 and L2 consisted of 0.0, 0.1, 0.3, 0.6, 1.0, 1.5, 2.0 and 3.0 meters below the liner surface. Installation depths at location L3 consisted of 1.0, 3.0, 5.0 and 7.0 meters below high water level. Installation depths at location L4 consisted of 2.0, 4.0, 6.0 and 8.0 meters below grade to coincide with the depths at L3. Additionally, nests of 3 to 4 piezometers where installed at increasing distances from each EMS to monitor any mounding formation. Nests generally covered depths between 3 meters and 8 meters below grade. During installation of the system, field hydraulic conductivity testing was preformed on the liner at each site.

In June 1998 the first installation in a new facility was installed in the EMS at Big Sky Farms Clearfield Feeder Unit near Kelvington, Saskatchewan. Continuous core samples were retrieved from the deepest hole at each instrumentation location and sent to the PFRA geotechnical testing laboratory in Regina. Installations at locations L1 through L4 were completed in approximately 2 weeks. Trenches to run the pneumatic lines, temperature and ORP wires and the water sampling tubes were 100mm wide by 300 mm deep, backfilled with sand-bentonite mixture and then covered with fill material. Care was taken to place bentonite plugs at the junctions in the trench where new lines joined the trench. Trench backfilling from the last installation to the access manhole on the berm was attempted using only the excavation equipment for compaction. This portion of the trench had been excavated with a backhoe and was approximately 600mm wide and 0.6 meters to 1.5 meters deep. This proved to be inadequate as seepage occurred through the backfill near the manhole and flooded the manhole when the EMS was filled. The backhoe trench was re-excavated, the lines rebedded in pure bentonite powder and the trench backfilled by compacting thin layers of fill with hand-

operated gas powered compactors. Piezometer nests were installed at the site in July and August 1999 to monitor groundwater-mounding conditions.

System installation at Genex Swine Bon Accord Nucleus Unit near Ituna, Sask. occurred in July and August 1999. This system was installed in the same manner as the first system with the exception that all trenches were only 100 mm wide and 300 mm deep in ponded areas and the trench reached a depth of 1 meter at the crest of the berm prior to entering the manhole. All trenches were backfilled by bedding the lines in bentonite powder and then filling the trench with compacted fill placed in thin layers and compacted with pneumatic compactors.

Installation of the system in the EMS at PSC Elstow Research Farm near Elstow, Sask. occurred in November and December 1999. Additional drilling to install piezometer nests was conducted in February and October 2000. Pneumatic piezometers were used at the nested piezometer locations to monitor groundwater mounding conditions as this site consisted of highly plastic clay (CH) over dense till (also CH) and the project team felt the conventional standpipes would respond too slowly.

Installations at the older sites consisted of installation of nested conventional standpipe piezometers starting as close to the storage as possible and extending out with nest every 3 to 10 meters. The sites chosen for investigation were both constructed in the mid-1980's. They had been constructed similar to an earthen borrow pit with steep side and sloped ends. Neither EMS was constructed with a liner of any kind. The sites chosen were Site No. 9 near Hepburn, Sask. and Site No. 1 near Saskatoon, Sask. These sites had been initial investigated by UMA Engineering Ltd. under a Canada-Saskatchewan Green Plan project in 1994. Site No 1 had been further investigated by PFRA in 1993.

In August 1998, piezometer installation and soil sampling occurred at Research Site No. 9. The EMS at Site No 9 had been constructed in 6 meters of unconsolidated stratified glacial till material overlying 3 meters of over consolidated clay till. Beneath this layer exists a confined silt and sand layer to a depth of 14 meters. Below this is unoxidized clay till. Seepage at the site was occurring in thin (50 to 100 mm) sand lens at an elevation similar to the bottom of the

EMS. No evidence was found that suggested seepage was occurring vertically. Complicating factors at this site were the stockpiles of solid manure on one side of the storage, a main underground power line on two sides and the fact that the extent of the groundwater mounding around the EMS was directly dependent on the liquid level in the EMS. For these reasons only 21 piezometers were installed at this site and all piezometers were installed in the same transect.

Installations at Research Site No.1 for this project started in February 1999. The EMS at Site No 1 had been constructed surficial sands (SM and SPSM) overlying layered lacustrine deposits of silts and clays. This site offered a very unique opportunity as the fairly permeable sands at this site contained approximately 8% smetitic clays giving the material a CEC of approximately 8 meq/100g (or cmol/kg). This material also virtually eliminated the formation of groundwater mounding. The groundwater level at this site is slightly below the base of the EMS and does not appear to be influenced by the EMS liquid level. The plume at this site extends nearly 60 meters from the EMS and is contained from below by the clay (CH) lacustrine layers. This length of plume gave the project the opportunity to complete detailed characterization of the plume in two dimensions and produce a relatively clear picture the development of a plume. This site had been investigated under other projects and had 2 piezometers installed on the south and west side and one borehole through the base in March 1994. 10 more piezometers installed in February 1995 with 2 piezometers installed at a distance to determine groundwater flow (an abandoned well offered the 3rd point) and 8 piezometers in a "fan" configuration" on the south side extending approximately 78 meters from the storage. These installations indicated a plume extending south south-east from the storage. Additional activities completed under this project at the site included installation of 14 piezometers in nested configurations at 10-meter intervals on the south side of the storage (down gradient), 2 piezometers at one location on the north side (upgradient), and 2 piezometers at one location between a penning area and the storage. This work was completed in February 1999. In October 2000, 5 holes were excavated at the nest sites on the south side of the storage and soil gas sampling stacks were installed to measure gas levels in the soil from the surface down to the water table. In the late fall of 2001, 5 more holes were excavated at the nest locations and ORP microelectrode stacks were installed to attempt to

measure ORP profiles within the plume. Soil samples from these holes were taken at 0.5-meter intervals and sent to the Soil Science laboratory at the University Of Saskatchewan for analysis of ions in solution and ions on the soil exchange sites. This information is still pending at the time of this report.

In March 1999, 300 mm diameter columns by 4 meters high were constructed at the Prairie Agricultural Machinery Institute in Humboldt, Sask. Approximately 0.9 meters of soil was compacted into the base of the columns. Soil was compacted wet of the optimum moisture content and to approximately 95% of maximum Proctor density. Column No. 1 contained soils from the Big Sky Clearfield Feeder Unit site and was ponded with manure from the EMS at the same site. Column No. 2 contained soil from Research Site No. 1 and was ponded with manure from Big Sky 1 Farrowing Unit near Humboldt, Sask. Columns were monitored for hydraulic conductivity, ORP with depth and water samplers were taken at intervals to determine chemical breakthrough curves. Columns were dismantled in August 1999 and the columns frozen until they could be analyzed. In March 2000, the columns were sectioned every 25 to 50 mm and the samples analyzed for ions in solution and ions on the exchange sites.

Summary of Results

The chemistry of the "pore fluid" within EMS was similar for all the storages sampled. The most abundant ions, by far, are bicarbonate (HCO_3^-) and ammonium (NH_4^+). The next most abundant ions where found to be approximately one-third the activity or one-quarter the molality of bicarbonate and ammonium and included potassium (K^+), chloride (Cl^-) and, often, sodium (Na^+). All other ions appear to play a minor role. Commonly, levels of sulphate (SO_4^{-2}), calcium (Ca^{+2}) and magnesium (Mg^{+2}) are much lower in the EMS "pore fluid" than in the soil pore fluid.

Of the three EMS with systems installed at the new sites, only one has been filled to capacity since the installation of the monitoring system. This storage is the EMS at the Clearfield Feeder Unit. There have been several significant findings at this site to date:

1. Groundwater mounding occurred almost simultaneous to filling of the EMS. This means that the water table directly adjacent to high water level in the EMS was similar to the high water level. The water mound gradually decreased with distance and appears to meet the site water table at a distance of approximately 60 meters from the storage. This mound did not dissipate when the EMS was emptied. This means that groundwater discharge conditions exist within the second cell and possibly the first cell during periods when the cells are not full.
2. Seepage has occurred significantly more on the sides than on the base of the storage. Electrical conductivity values of water samples indicate seepage to depths of approximately 0.6 meters on the sides of the storage and 0.1 meters on the base of the storage within the first three years of operation.
3. Liner breaching as a result of damage to the liner has been indicated in the monitoring system in the first cell. Resulting seepage has infiltrated any available preferential flow paths adjacent to the liner and will continue to be monitored even after the liner damage has been repaired. The significance of this finding is that one of at least two things should happen. Either, agitation equipment needs to be altered with shields and flotation tires or agitation pads and access ramps should be installed at all EMS.

Investigation of the older sites has indicated that chemistry of the "pore fluid" of the source has a significant affect on the formation and transport of a plume. Significant findings from investigation of the plumes at these sites include:

1. Vertical flow of solutes seeping from an EMS can be assisted by gravity as the higher TDS seepage water will "settle" do the higher density.
2. The elevated levels of monovalent cations displace calcium and, to a greater extent, magnesium on the soil exchange sites. These displaced ions form a "hard water" front at the leading edge of a plume. Magnesium and calcium levels can exceed 100 and 10 times the normal levels respectively. Detection of this "hard water" may offer the ability for early detection of seepage plumes
3. Bicarbonate (HCO_3^-), chloride (Cl^-) and sodium (Na^+) follow standard advection dispersion transport with no noted retardation.

4. Transport of ammonium (NH_4^+) and potassium (K^+) is somewhat retarded. The ability of the soil to retard ammonium and potassium appears to be depleted exponentially as the pore water concentration increases. The significance of this is that as concentration increases, retardation decreases until a level is reach where transport is unretarded advective dispersive movement.
5. The above-mentioned process produces a relatively flat concentration front of ions advancing through the soil. This front nearly resembles "plug" flow with a velocity at C/Co= 0.5 of 0.65 and 0.5 the velocity of chloride for ammonium and potassium respectively. The significant difference from chloride movement being that the when the ammonium front does pass, the concentration will increase relatively quickly from background to very nearly the source concentration.

A question to arise from these studies has been in regards to the fate of the ammonium and potassium that finally resides on the exchange sites of the soil surrounding an EMS. Initial siting, operational procedures and decommissioning strategies all need to consider the long-term fate of these ions. By far the easiest solution still remains to place effort on the original siting of these facilities and proper engineering of soil liners and interceptor drain systems.

1.0 Introduction

Pork production in Saskatchewan has been increasing steadily over the past five years. In 1996 there were 829,300 head of hogs the province. As of April 1, 2000, the total was up to 1,039,800 head (Statistics Canada, 2000). This growth translates into an increase in manure production requiring storage and utilization.

The manure management component of an intensive livestock facility is one of the main items causing public concern. Earthen manure storages (EMS) are the most commonly used waste storage facilities in Saskatchewan for hog production facilities. The purpose of these facilities is to store liquid hog manure until it can be land applied as crop fertilizer. As a fertilizer, manure is relatively dilute. As an example, a typical liquid hog manure sample may be represented by 0.3-0.1-0.2-0.03 (N-P-K-S). As a liquid requiring storage, manure has relatively high levels of ammonium, potassium, bicarbonate, chloride and can have relatively high levels of sodium and sulphate depending on feed and water supplies. The storage of these relatively high nutrient content slurries is important for proper utilization but can cause concern for the protection of our groundwater.

As the livestock operations become more intensive and more widespread, more effort needs to be placed in determining the extent of seepage from established operations and to preventing seepage from new operations. Although recent investigations of earthen hog manure storages in Saskatchewan indicate there is minimal movement of solutes from storages (Maule and Fonstad, 1995, 1996) there are no studies that document the long-term performance and safety of earthen manure storages (Thu et.al. 1995). Past research in Saskatchewan (Fonstad and Maule 1995, 1996) has provided evidence to suggest that Saskatchewan soils are well suited for earthen manure storages and that seepage from these storages is limited to within several meters of the storage face. These studies suggest that in certain instances there may be no advantage to lining earthen manure storages. If these suggestions could be verified, they would mean substantial cost savings to producers, confirm that there are limited environmental concerns and provide new guidelines for the siting of earthen manure storages.

The lack of data associated with long-term performance of EMS has also hampered development of new facilities, as developers have no reference to satisfy the concerns of the neighbors of the proposed facility.

The need for a study to monitor long-term performance of EMS was expressed by Heartland Livestock (a division of Sask Wheat Pool) and the Geotechnical Unit of the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada. The Department of Agricultural and Bioresource Engineering of the College of Engineering at the University Of Saskatchewan was approached to act as principal investigators with support from PFRA's Geotechnical Unit. In May 1997 the department submitted a proposal for funding to the Agricultural Development Fund (ADF) of Saskatchewan Agriculture and Food. This proposal was supported by PFRA, Heartland Livestock, Quadra Group, Big Sky Farms Inc., and Sask Pork. Funding support was approved in August 1997 from ADF and Sask Pork. In early 1998 Big Sky Farms expressed interest in cooperating in the research both financially and by allow the research team to use one of their feeder sites. The first monitoring system was install at this site in June 1998 by PFRA and the University of Saskatchewan. Following this, Genex Swine and Prairie Swine Center Inc. expressed interest in cooperating in the same manner with the use of an EMS at a 1200 sow genetics nucleus unit and a 600 sow farrow to finish research facility respectively. Monitoring systems were installed a these location in July and November 1999 respectively. During 2000, additional drilling was completed at all three sites as required to improve/complete the monitoring systems.

As a compliment to the monitoring of new storages, the research team felt that the detailed investigation of at least two "older" storages would be beneficial to assist in interpretation of the data gathered at the new sites. Two sites were chosen near Saskatoon. Both sites had been in use since the early 1980's and neither storage was constructed with a liner. Site No. 1 is south of Saskatoon, is a single cell storage and was constructed in surficial sands over lacustrine sand, silts and clays at depth of 6 to 8 meters below grade. The surficial sand at this site act as an unconfined aquifer with a water table 2 to 3 meters below grade. Site No. 9 is

north of Saskatoon, is a single cell storage and was constructed in stratified till materials over a 5 meter thick confined aquifer at 9 meters below grade.

Finally, laboratory work was initiated to simulate an EMS profile using large columns. As a compliment to the EMS profile laboratory set up, several EMS were sampled from a boat to gain a characterization of the chemistry and solids profile within an EMS.

This report outlines the rational and designs of each component of the research, along with installation and sampling protocols and initial/final results. A more detailed report is available for viewing at the office of Saskatchewan Agriculture and Food Agriculture Operations and Agriculture Development Fund, the Geotechnical Unit of PRFA and the Department of Agricultural and Bioresource Engineering at the University of Saskatchewan.

2.0 Objectives

The main objective of this project was to provide data regarding the long term performance and safety of earthen hog manure storages constructed in Saskatchewan.

This objective were be achieved by the:

- Design and installation of a monitoring system to observe solute movement from three newly constructed earthen hog manure storages,
- Detailed investigations of solute plumes at two established sites, and
- Laboratory work to assist in the understanding of the processes affecting the rate of seepage from earthen hog manure storages.

3.0 Technical Report

3.1 Monitoring System Design for Newly Constructed EMS

The initial system proposed involved the installation of gravel subdrains (lysimeters) below the EMS soil liner with lateral drains to manholes or vertical piping to measure piezometric head and allow water sampling (Figure 3.1). This system would be relatively inexpensive and could be installed with a small backhoe and manual labor.

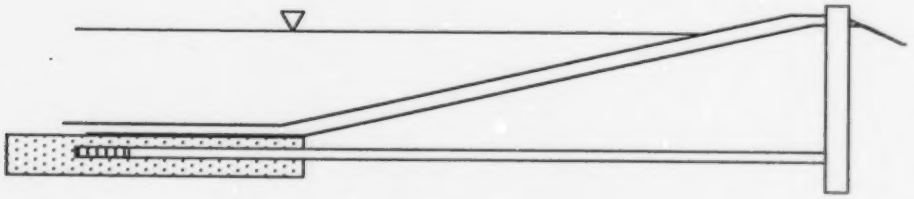

Figure 3.1 – Initial proposed monitoring system

This system had several shortcomings. First, the installation and back filling of a trench deep enough to allow gravity drainage of the gravel beds could potentially leak more than the liner giving erroneous readings. Secondly, the gravel beds would only allow measurement at breakthrough to the beds unless several beds were "stacked" in one location. This would entail even deeper trench excavation. Third, the gathering of water in drain tubes exposed to ambient air would cause chemical transformations defeating the attempt to monitor chemical changes in the soil pore water below the EMS. Fourth, the drained gravel bed lysimeters installed below a clay rich earth liner could produce a capillary break were by the capillary suction in the clay was strong enough to resist flow into the unsaturated gravel bed. This capillary action had recently been shown to cause preferential flow in the smaller pores of the clay resulting in flow around the gravel bed lysimeter. Although the budget had been based on this system, the project team felt that installation of systems of this type would not give the required information and had the potential to give erroneous readings.

The second monitoring system considered was based on the hypothesis that the EMS would produce a "bulb" of ion rich water around the EMS that would grow with time. This bulb would slowly progress into the vadose zone (unsaturated zone) until it reached the water table and began to eventually form a groundwater mound like situation around the EMS. Based on this hypothesis conceptual design of an unsaturated system was conducted (Figures 3.2 and 3.3). The system involved construction of a pier like structure into each cell of the EMS. All instrumentation could be accessed from this pier. Instrumentation included suction lysimeters at various depths for soil water sampling, soil gas samplers at various depths, time domain reflectometer (TDR) probes at various depths to monitor changes in moisture and electrical conductivity (EC), thermal conductivity sensors to measure soil suction, and vertical access tubes for down hole electro-magnetic (EM) readings to monitor changes in electrical conductivity (EC).

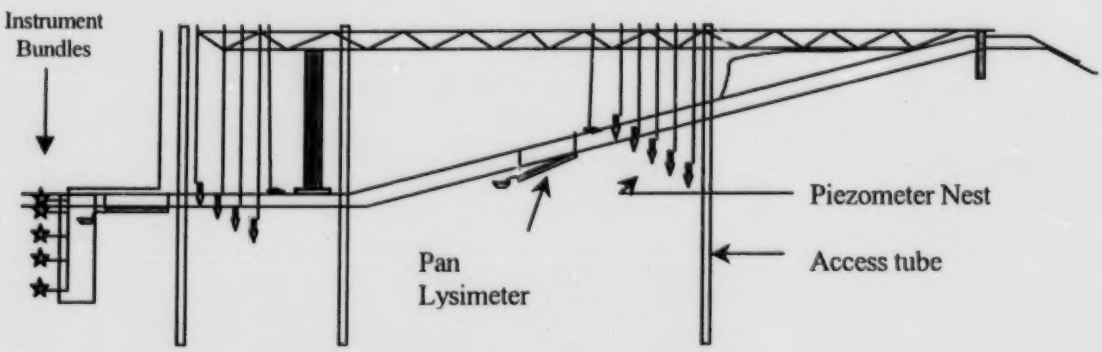

Figure 3.2 – Monitoring system considered for an unsaturated soil condition

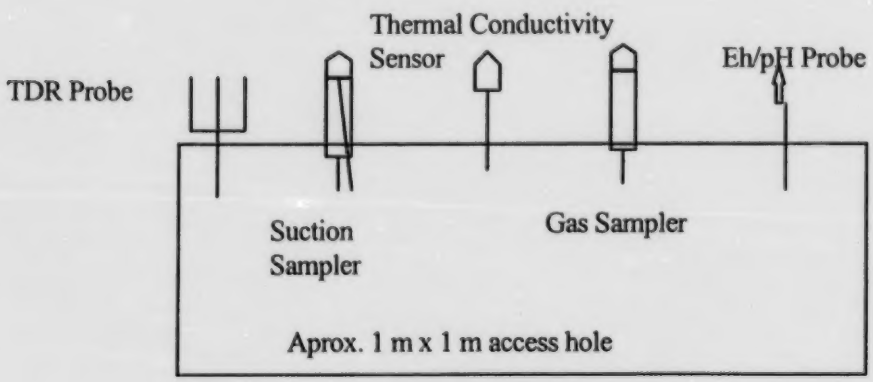

Figure 3.3 – Instrument bundle for unsaturated system

The resulting system was relatively expensive in terms of both materials and installation time, ice could damage most of the instruments used and most of the instruments did not have the accuracy required at soil saturations above 90 to 95%.

The project team decided to review the actual site conditions at as many previous EMS sites as possible. A review of over 25 sites of EMS constructed in clayey material revealed that most sites exhibited a water table between 3 and 6 meters below grade and that the soil at the sites was normally 95% to 98% saturated. This meant that very little seepage would produce a pressure wave resulting in groundwater mounding and 100% saturated conditions. If this was the case and given the fact that any unsaturated flow prior to mounding would be insignificant, the project team again decided to redesign the monitoring system. This new system would be intended for saturated conditions and need to provide hydraulic pressure head at the installation depth, provide a water sample not affected by ambient air and indicate temperature and ORP at the sampling point. In addition to pressure head, temperature and ORP measurements, water sample alkalinity, tempertature, pH, and EC would be taken at the site during sampling. All other chemical data could be obtained from analysis at the laboratory.

The system used bundled a short (450 mm long x 50 mm dia.) well screen with a pneumatic piezometer for pressure measurement, two-3.2 mm diameter plastic tubes for suction extraction of water samples, a thermocouple and a platinum ORP probe (Figure 3.4). In installations where there was no fluid ponding, the pneumatic piezometer was not required and was replaced by a standpipe. This system offered:

- relatively precise measurement of parameters and a good quality water sample,
- simple installation and could be installed after construction of the storage was complete,
- measurement and sampling would be simple,
- temperature and ORP could be automated, and
- system materials cost would allow installation of up to 24 sample bundles in each cell of a two-cell storage.

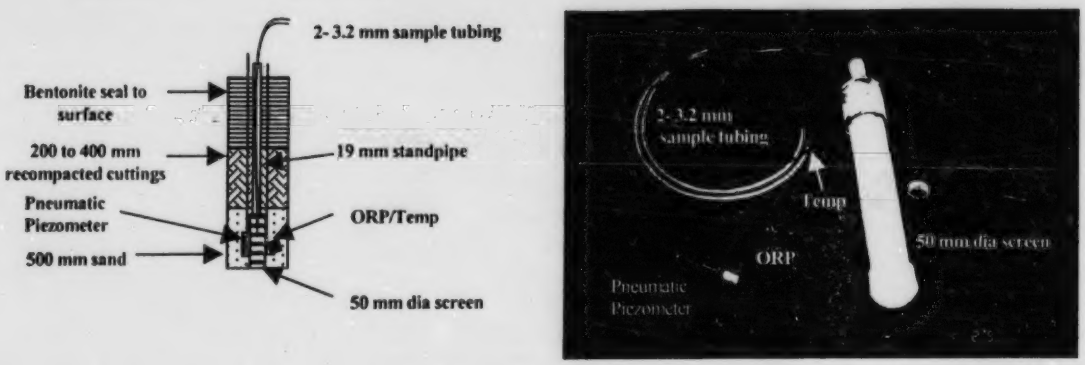

Figure 3.4 - Proposed instrument bundle for monitoring in saturated conditions

There was some concern expressed that dissolved gas sampling would not be possible in areas below the EMS and the accuracy and interpretation of the ORP measurement was not a proven technology. Mr. Steven Gibbard, P.Eng of PFRA decided to complete a Master's Thesis on the topic of ORP measurement below earthen liquid storages to attempt to increase the probability of successful ORP measurement.

The research group felt this design offered the best chance for a successful installation, should be durable and offer meaningful results. Figures 3.5 and 3.6 show installation locations. Installations were targeted for a location at least five meters into the bottom of the storage (L1), at the mid-point of the sidewall (L2), at high water level (L3) and four meters back from high water level (L4). At locations L1 and L2, bundles were installed at 0.0m (surface), 0.1m, 0.3m, 0.6m, 1.0m, 1.5m, 2.0m, and 3.0m depths. Bundles at location L3 and L4 were installed at 1m, 3m, 5m, and 7.5 m below high water level to coincide with installations at L1 and L2 (Figure 3.5). At each site, several nested piezometers were installed at various distances up to 60 meters from the storage to measure groundwater mounding.

The instrumentation placed at each location is as follows:
Locations 1 and 2:

- Redox probes, thermocouples and suction tubing placed at 0, 0.1, 0.3, 0.6, 1, 1.5, 2.0, and 3.0m below liner surface.
- Pneumatic piezometers at 0, 0.1, 0.6, 1.5 and 3.0m below the liner surface.

Location 3:

- Redox probes and thermocouples at depths of 1.0, 3.0, 5.0, and 7.5m below liner surface.
- Standpipe piezometers with 0.5m screens at all locations for direct retrieval of water samples.

Location 4:

- Redox probes and thermocouples at depths of 3.0, 4.0, 6.0, and 8.5m below liner surface.
- Standpipe piezometers with 0.5m screens at all locations for direct retrieval of water samples.

Piezometer nests:

- Nested piezometer locations were decided in the field after analysis of test hole logs.
- Piezometers were constructed with 450mm long by 50 mm diameter screens and sand packed to a produce an effective screen length of 500 mm.

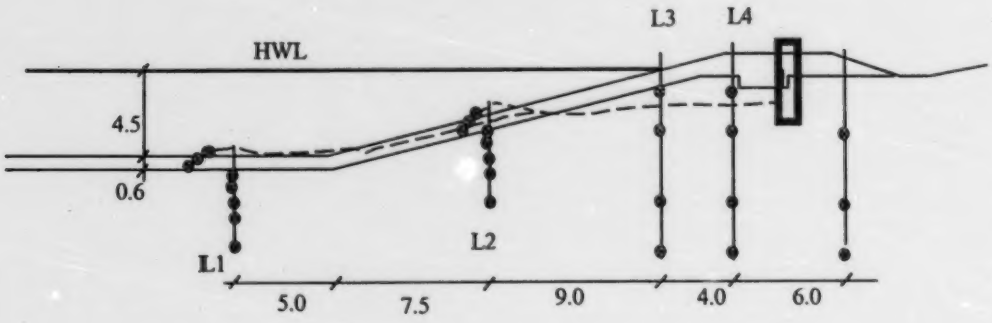

Figure 3.5 – Location of instrument bundles installed in earthen manure storages

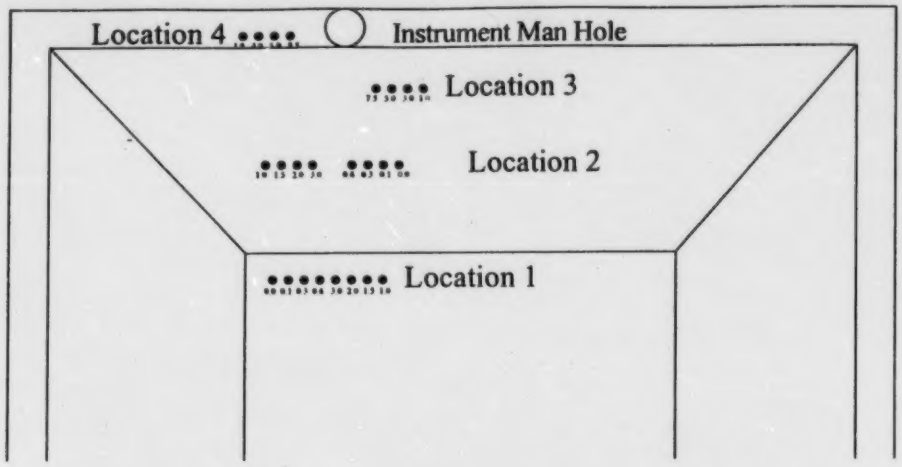

Figure 3.6– Test hole layout at each location

At the completion of construction of the liner at each site Single Sealed Ring Infiltrometer/Air Entry Permeameter (SSRI/AEP) readings were taken in several locations in each cell of the storage (Figure 3.7). These measurements indicated the liners at the sites tested had initial hydraulic conductivities after construction in the order of $5x10^{-8}$ cm/s. The liner at the PSC Elstow site could not be tested due to frost conditions at night.

Figure 3.7 – SSRI/AEP measurements of a soil liner for insitu hydraulic conductivity

Drilling was accomplished using a small auger rig for shallow holes (<1.5 meters) and a cable tool rig (PFRA) for all deeper holes (Figure 3.8). The deepest hole at each installation location was sampled continuously using brass liners. These liners were placed in cold storage (5 °C) (Figure 3.9) and then extruded (Figure 3.10) and analyzed at the PFRA geotechincal laboratory.

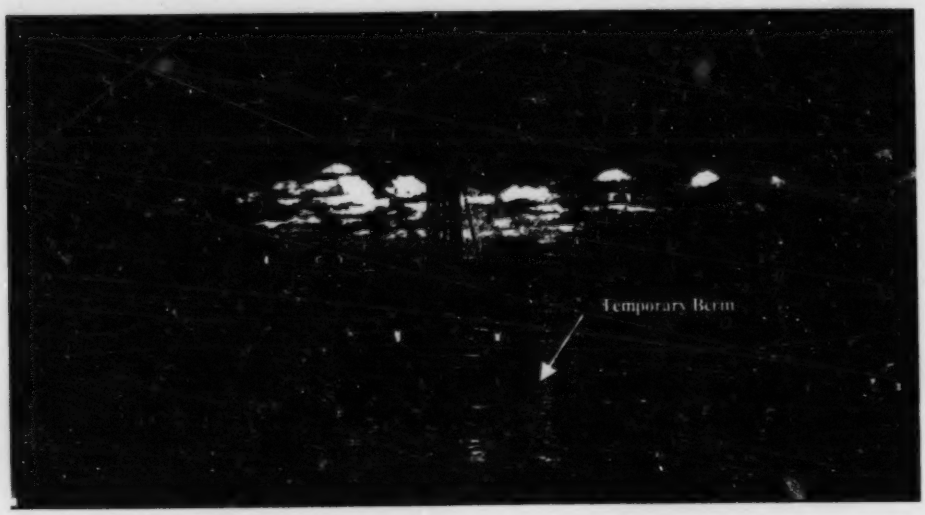

Figure 3.8 – Drilling on side slope with cable tool rig

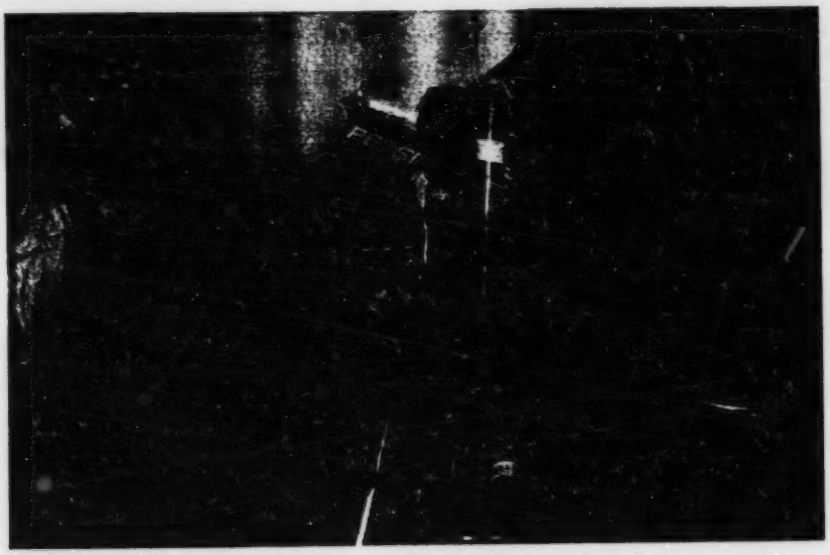

Figure 3.9 – Soil samples in brass liners in cold storage

Figure 3.10 – Extruding unoxidized till (left) and a sample of fractured oxidized till (right)

At the completion of each hole, a sampling bundle was placed in the bottom and sand packed to approximately 50 mm above the screen. Cuttings saved from the installation depth were packed on top of the sand to a thickness of approximately 100mm to prevent bentonite interference in sample water chemistry. The hole was then sealed to the surface with bentonite chips. Once all the installations were complete, small trenches were excavated (100mm wide by 300mm deep) from each test hole to a manhole on the berm and all tubing and wiring was then place in the trenches and covered with bentonite powder. The trenches were then backfilled in thin lifts with compacted clay liner material (Figure 3.11).

Figure 3.11 – Trench excavation and manhole installation at Clearfield Feeder Unit.
(Subsequent installations used a 100mm wide trench all the way to the manhole.)

A pin connector was placed on all thermocouples and another was placed on all redox probes in the manhole. These probes can now be read much faster by using the pin connectors to hook the probes to a datalogger, which can then be read by a computer. Pneumatic piezometers and water tubings were each connected to boards to ease data collection (Figure 3.12). Water levels are read with either a pneumatic piezometer reader of a standard water level tape.

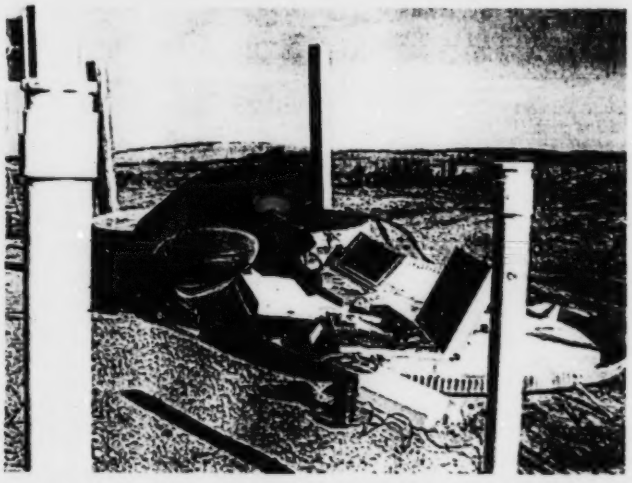

Figure 3.12 – Reading ORP and thermocouples using data collector and lap top computer

3.2 Big Sky Farms Clearfield Feeder Unit

3.2.1 Site Description

The Big Sky Clearfield site is located near Kelvington, Saskatchewan on SE 13-36-12-W2. This 9600 pig feeder barn is serviced by an EMS facility with storage capacity of 33,400 m^3 (7.35 million gallons) with one (1) metre of freeboard above the high water level and an allowance of 0.5 metres of permanent storage in the bottom. This volume is intended to be sufficient for 400 days of effluent storage. The top of the storage dykes are set approximately one (1) metre above existing ground elevations to ensure no infiltration of surface water runoff. Where dykes were excavated into the ground, drainage is provided around the perimeter of the storage. Existing natural surface water drainage is to the west and north-west

and has been improved to ensure surface water does not pond near the storage. The storages were constructed during the summer of 1998.

3.2.2 Site Background

This site is located on the northern fringe of the Quill Lake Plain. This physiographic region is characterized by the presence of glacial till and glaciofluvial plains. The topography is gently undulating to rolling. The top 60 meters at this site consists of glacial till and stratified drift underlain by approximately 180 meters of bedrock from the Riding Mountain Formation.

A subsurface soils investigation was conducted by UMA Engineering Ltd. and P. Machibroda Engineering Ltd. at this site in spring, 1996. Drill logs at this site show 100 to 150-mm of organic topsoil followed by clay or glacial till. Some clay lenses were encountered within 0.4 to 1.8 meters below grade and were underlain by glacial till. Glacial till was encountered to the bottom of all test holes (6.1 to 13.0-m). Silt and sand lenses were encountered at various depths throughout the till. Cobblestones and boulders were also found.

The till at this site was found to have clay contents of 21% to 31% and a fines percentage of 56% to 76%. The plasticity index ranged from 13 to 18. A rising head response test performed on Test Hole 12A showed a bulk saturated hydraulic conductivity of 1.3×10^{-6} cm/s. The following table provides results of soil laboratory analysis.

Soil laboratory analysis:

Test Hole No.	Depth (m)	CEC (meq/100g)	Standard Proctor - Moisture Density			
			Moisture Content (%)	Dry Density (kg/m^3)	Void Ratio	Porosity (%)
12A	0-5.0	14.4	13.2	1870	0.47	32

Multiple groundwater systems exist above and below the glacial till at this site. The top system is a phreatic groundwater table occurring 3.0 to 6.0-m below existing grade. This is a low

yielding, highly mineralized system. Water is also encountered within the sand and gravel deposits located throughout the till.

Groundwater supplies both human and agricultural requirements in this area. Saskatchewan Water Corporation has record of six water wells within 1600 m of this site. Four of these wells were producing wells, with recorded yields of 1.1 to 1.9 L/s. Depths ranged from 24.4 to 65.5 m below grade. The fifth well was drilled to a depth of 7.3 m with no yield reported and the sixth was a test boring that reported clay throughout entire drill depth.

3.2.3 Installation and Chronology of Events

Liner construction was completed during June of 1998. Immediately following liner completion, PFRA and the U of S installed the monitoring system in Cells 1 and 2.

During the summer of 1999, liquid from the EMS's was found to be accumulating in the manholes installed with the monitoring systems the previous year. It was determined that the deep trench excavated to carry the instrumentation into the bottom of the 3m deep manholes was leaking. As a solution, the trench was reopened, sealed with bentonite powder and recompacted. Also, concrete was poured into the manholes to seal the opening of the trench and prevent any further leaking. Due to this problem, the design of the system was altered at other sites to allow for a shallower manhole installation.

Additional test holes were completed on July 5 to 7 and again on August 26 to 31 of 1999 by PFRA and U of S. Standpipe piezometers were installed in 17 of these, with pneumatic piezometers placed in two. These additional piezometers were placed around the primary cell to more closely monitor groundwater mounding. A location plan of all surrounding standpipe locations is provided in the appendices.

Sampling Events

Oct. 28, 1998:	water levels, temperature, redox
Dec. 2, 1998:	water levels
June 21-22, 1999:	water levels, water samples
July 5, 1999:	water levels
July 21, 1999:	water levels
Sept. 15-16, 1999:	water levels, water samples, temperature, redox
Oct. 25, 1999:	water levels
Nov. 25, 1999:	water levels
Dec. 22, 1999:	water levels, temperature, redox
April 18, 2000:	water levels
July 2000	water levels, water samples
Oct. 6, 2000:	water levels
Oct 24-26, 2000:	water levels, water samples, temperature, redox
Nov. 5, 2000:	water levels
Jan. 10, 2001:	water levels, temperature, redox

The EMS at this site has been emptied or drawn down in of each year.

3.2.4 Hydrology Results

Groundwater mounding has occurred at a rate equal to the rate of filling of the EMS (Figure 3.13). It is speculated that this is due to the near saturated conditions in the surrounding soils allowing immediate response when a very small amount of fluid is added to the system. It is important to note that groundwater mounding does not indicate leakage but does reveal the hydraulic gradients affecting potential seepage.

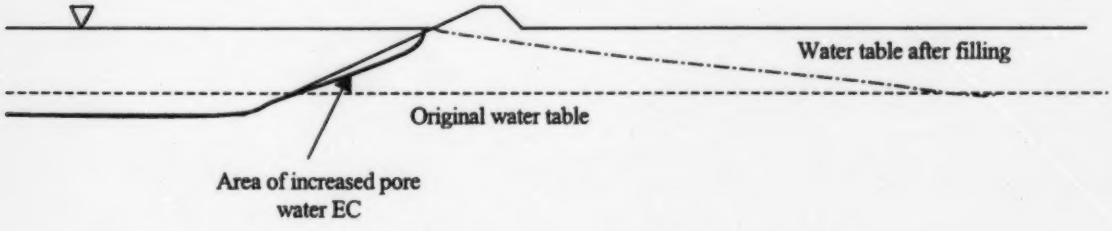

Figure 3.13- Groundwater mounding versus increased soil salinity at Clearfield Feeder Unit site

3.2.5 Groundwater Chemistry

1998 and 1999 electrical conductivity readings indicate minimal infiltration on the floor of the storage and infiltration to 0.3m on the sides. A higher rate of seepage from the sides of the storage is expected due to liner desiccation from freeze-thaw cycles. Data collected in the fall of 2000 from the instrumentation at the lowest depth in Locations 1 and 2 at Cell 1 had electrical conductivities reminiscent of the liquid within the storage (Figure 3.14). Comparison of these conductivities with the earlier conductivities obtained in water from the same location show that this high conductivity is likely not caused from a pocket of highly mineralized groundwater. Field observations also indicate that water samples retrieved from these locations were similar in color to the liquid waste in the cell. Observations of the sides of the storage indicate this seepage is likely caused by liner erosion resulting from pumping fluid from Cell 2 to Cell 1 during emptying. The fact that the seepage appears to be in granular lenses or between the liner and the original soil surface would appear to indicate the seepage is the result of liner damage in a particular area allowing seepage into a certain soil strata. Big Sky Farms intends to have the liner repaired when the storage has been emptied. The U of S will continue to monitor this site for at least the next five years.

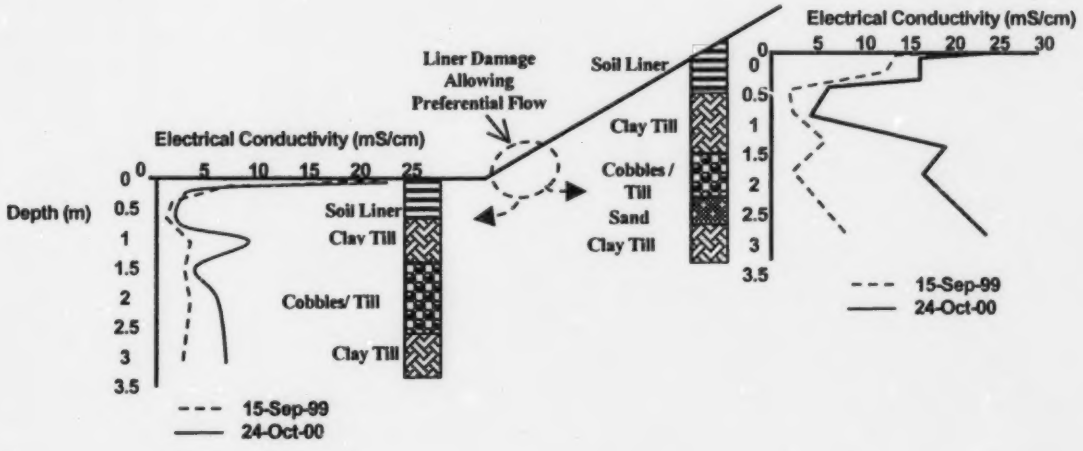

Figure 3.14 – Seepage detected in the fall of 2000 in Cell 1, Clearfield Feeder Unit

3.3 Genex Swine - Bon Accord Nucleus Unit

3.3.1 Site Description

The Bon Accord Nucleus Unit was constructed by the Genex Swine Group approximately 6.5 km WNW of Ituna, and 3.4 km SSE of Jasmin, Saskatchewan during the summer of 1999. The earthen manure storage (EMS) was constructed on the NW 27-25-12 W2M to provide 400 days of effluent storage for a 1200 sow farrow to finish nucleus unit. The EMS is a two cell (1/3 – 2/3) facility with a storage volume of approximately 54,720 m^3 (12 million gallons).

Topsoil was stripped from the surface before storage construction was begun. After excavation to the storage depth, the clay till present at the site was compacted to form a 600 mm thick liner in the storage. Liner construction was performed as per standards recommended by the consulting engineers.

3.3.2 Background Information

The property is situated within the physiographic region referred to as the Touchwood Hills Upland. This is characterized by rolling morainic plains and till plains with moderately undulating to strongly rolling topography. The upper 200-m consist of glacial till and stratified drift followed by approximately 150-m of silty clay-shale of the Lea Park Formation - Upper Colorado Group

Initial test drilling for regulatory purposes was completed at this site by P. Machibroda Engineering Ltd. to determine any environmentally sensitive aspects of the area. The site was found to have 300-400mm of topsoil, overlying variable lacustrine and alluvial sands and clays extending to depths of 0.8 to 1.0 meters below ground surface. Beneath this are two till layers. The upper till layer is oxidized to a depth of 5 to 7 m with the lower 1 to 3 m unoxidized. The lower till strata was of similar characteristics to the upper till and continued to

a least 11.2 m below grade, oxidized to the depth of exploration. At the till contact a discontinuous sand lens ranging from 0.0 to 1.5 m in thickness was encountered.

The glacial clay till at this site was determined to have 22% to 31% clay content, 56% to 63% fines, and a Plasticity Index of 12% to 16%. A rising head test performed on test hole 98-3 indicated a bulk saturated hydraulic conductivity of 4.4×10^{-5}cm/s. The following are typical laboratory results for the soils at this site:

Soil laboratory analysis.

Test Hole No.	Depth (m)	Cation Exchange Capacity (meq/100g)	Standard Proctor - Moisture Density			
			Opt. Moist. (%)	Dry Density (kg/m^3)	Void Ratio	Porosity (%)
98-2	4.5-6.0	10.3	11.9	1911	0.44	31

The static water table is approximately 5.0 to 8.0 m below ground level, with flow in an east/southeast direction at a gradient of 0.001. A downward hydraulic gradient was also noted, indicating a groundwater recharge area.

Due to the presence of the sand layer between the two till layers and the possibility of contamination, it was requested by Genex Swine that a monitoring system be installed at this site.

3.3.3 Chronology of Events

Liner construction was completed in July, 1999. Immediately following liner completion, PFRA and the U of S installed the monitoring system in Cell 1 and Cell 2. The manholes on the berms of the EMS's were installed at a depth of only 1.5m below the top of the berm to prevent the need for the deep trench. Trenches to connect the instrumentation to the manhole were excavated into the liner and were approximately 100 mm wide by 200 to 300 mm deep. Poly-Gel bentonite powder was poured into the trenches until all lines were covered. The trenches were then completely filled with liner material, which was packed in layers with a pneumatic tamper.

Additional test holes with standpipe piezometers were completed on August 23 to 26 of 1999 by PFRA and U of S. These additional piezometers were installed to more closely monitor groundwater mounding.

Sampling Events

Oct. 27-28, 1999:	pneumatic piezometers, water levels, suction samples
July 24-25, 2000:	pneumatic piezometers, water levels, water samples
Sept. 9, 2000:	pneumatic piezometers, water levels
Nov. 7, 2000:	pneumatic piezometers, water levels
Jan.4, 2001:	pneumatic piezometers, water levels

October 1999 measurements were taken to be used as background readings, as the EMS was not yet in service. Very few water samples could be obtained from beneath the storage due to lack of water at the suction tubing elevations. At this site, the water table is below the instrumentation elevations. The Cell No 1 of the EMS at this site was emptied during the last week in October, 2000. At this time Cell No 2 was not full.

3.3.4 Results

There are very few results to report at this site, as the EMS had not been in use long enough to obtain significant data. This site will continue to be monitored under further funding through ADF and Sask Pork.

3.4 Prairie Swine Centre Elstow Research Farm, Inc.

3.4.1 Site Description

Prairie Swine Centre (PSC) Research Farm is located approximately 3-km northeast of Elstow, Saskatchewan on the SW 24-35-1-W3M. This is a 600 sow farrow-to-finish research and production unit that is serviced by an EMS providing 400 days of effluent storage which equates to approximately 22,000m^3 (4.9 million gallons).

The entire EMS was lined with a 600 mm thick compacted clay liner using material excavated from the EMS site.

3.4.2 Site Background

The land surface at this site is defined as moderately rolling to undulating with glacial lacustrine - alluvial plains. Examination of an aerial photograph of the area reveals a surface with many potholes, indicating poor surface drainage. The property is located in the Saskatchewan Rivers Plain physiographic region. Surficial soil is characterized as variable textured lacustrine and alluvial sands, silts and clays. The upper 30-40-m of this site consists of glacial till and stratified drift. This is underlain by 30 to 50-m of the Bearpaw formation (non-calcareous silty clay shale), followed by 20 to 30 m of the Judith River formation (non-calcareous sand, silt and clay) and 270-m of the Lea Park Formation - Upper Colorado Group (silty clay-shale).

The initial site investigation at this site for regulatory approvals was performed by P. Machibroda Engineering, Ltd. Drill logs from test holes at the EMS site showed 200 to 250-mm organic topsoil followed by medium to highly plastic clay to a depth of 5.5 to 7.6-m below grade. This was underlain by glacial till which extended the depth of exploration (15.1-m below ground surface).

The upper soils have clay contents from 37% to 57%, 93% to 100% fines, and a plasticity index of 21% to 46%. Values for the lower till zone are 18% to 39% clay, 62% to 94% fines, and a plasticity index of 10% to 14%. Based on these values, the bulk hydraulic conductivity is estimated at 10^{-6} to 10^{-8} cm/s. Standard Proctor moisture density and cation exchange capacity was determined for soil at two depths in test hole 10. Typical soil analysis test results are given below.

Soil laboratory analysis:

Test Hole No.	Depth (m)	CEC (meq/100g)	Standard Proctor - Moisture Density			
			Opt. Moist. (%)	Dry Density (kg/m^3)	Void Ratio	Porosity (%)
10	2.0-4.5	18.7	24.3	1558	0.82	45
10	5.5-7.0	22.1	26.4	1515	0.85	46

Groundwater is encountered within and above the glacial till strata of this site. The upper groundwater table is phreatic, found 5 to 12 meters below original ground surface. Two wells within 1.6-km of the property were found in Saskatchewan Water corporation Records. These wells were completed at 21.9 and 36.6 meters below ground, both with pumping rates of 45 litres per minute. An additional well was reported within the range of 1.6 to 3.2-km of the site, with a completion depth of 38.1meters.

3.4.3 Chronology of Events

Liner construction was completed during November of 1999. Immediately following liner completion, PFRA and the U of S installed the monitoring system in Cell 1 and Cell 2 at the locations shown in Figure 3.15.

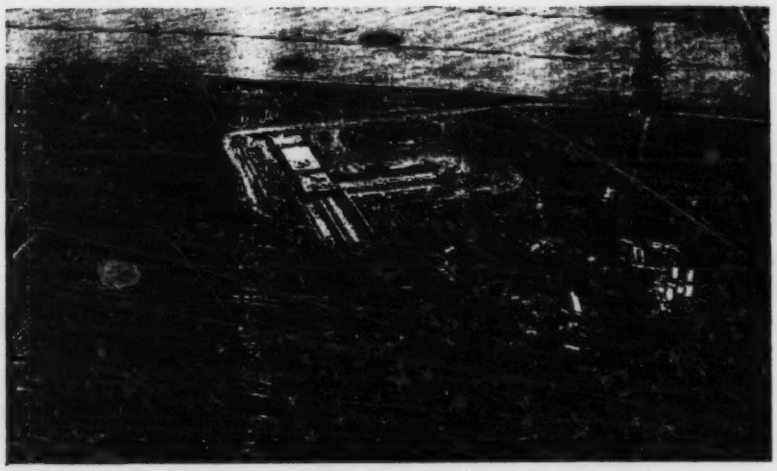

Figure 3.15 – Areal view of PSC Elstow Research Farm showing location of EMS monitoring system

Additional test holes with standpipe or pneumatic piezometers were completed on October 11 and 12 and October 25 and 26, 2000 by PFRA and U of S. These additional piezometers were installed to more closely monitor groundwater mounding.

Sampling Events

April 11, 2000:	water levels, water samples
July 21, 2000:	water levels, water samples
Sept. 11, 2000:	water levels
Jan. 12, 2001:	water levels, temperature, redox

The EMS started receiving manure between May 8 and May 15, 2000, and Cell 1 was emptied for the first time in the fall of 2001. Very little fluid had accumulated in Cell 2 at this time.

3.5 Research Site No 9

3.5.1 Site Description

Site No. 9 is an established EMS located near Hepburn, Saskatchewan. It was constructed in a stratified glacial drift material in the early 1980's. No further description of the location of this facility will be provided nor will the legal land description as part of our access agreement with the owner.

3.5.2 Site Background

The upper 60-100m of this site consists of stratified drift. This is followed by approximately 200m of the Lea Park Formation - Upper Colorado Group (silty clay - shale).

Test drilling revealed that the site is mantled with 3 to 5 meters of stratified oxidized till material followed by 3 to 4 meters of oxidized till overlying a lacustrine clay, silt and sand deposit from 7.5 to 14.5 m below the grade. This is followed to un-oxidized clay till to depths of at least 15.5 meters below grade (maximum depth of excavation).

3.5.3 Monitoring System Installation

In August 1998, PFRA and the U of S installed 50 mm diameter monitor wells on the south side of the EMS (Figure 3.16) using a truck mounted cable tool rig (Figure 3.17). This location was chosen from information provided by a preliminary study completed by UMA Engineering in 1994. Soil cores were taken at each nest location in 60 mm x 750 mm brass liners, which were then sealed and stored between 2°C and 6°C. Cores were extruded in the PFRA laboratory in Regina and samples were sent to the U of S Soil Science Laboratory for 2M KCl extraction. The remaining soil was analyzed by PFRA for grain size, Atterberg limits, density, specific gravity, moisture content, and hydraulic conductivity.

Figure 3.16 – Test Drilling at Site No. 9

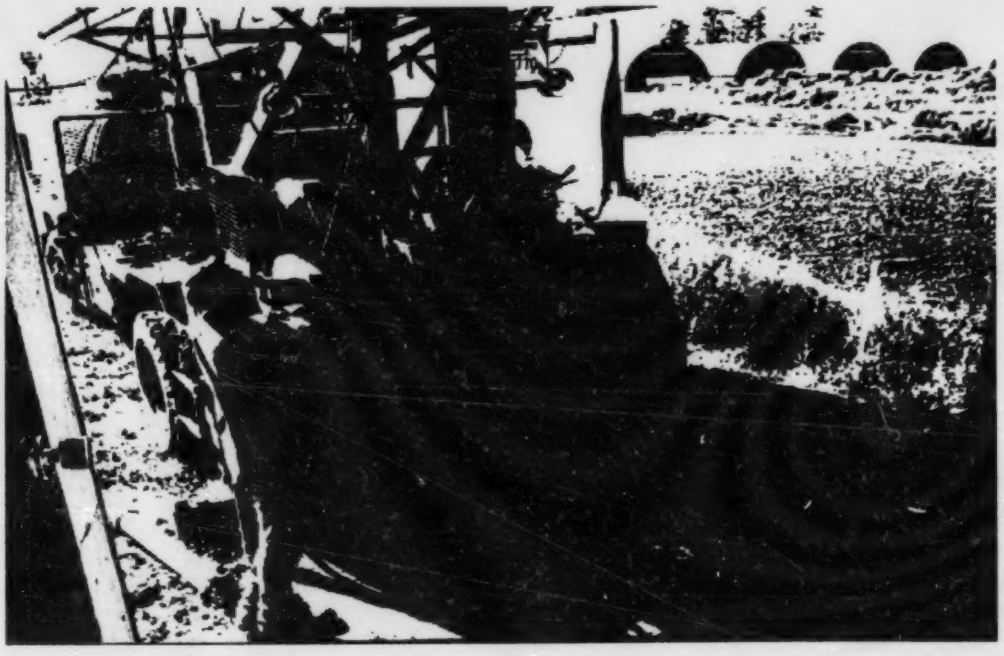

Figure 3.17 – Cable tool rig used for sampling and test hole installation

On February 25 and 26, 1999, drilling was completed through the ice in the EMS. Drilling was accomplished with a rotary drill rig using a hollow stem auger and Shelby tubes for sampling. The rig was parked on the ice surface of the EMS and the hollow stem auger drilled down to the soil surface. Shelby tube samples were taken and the auger drilled down to the level of the sample. This procedure was repeated to a depth of 3 to 4 m. Samples were placed in cold storage until extrusion was possible. The finished test hole was then cleaned out and an instrument bundle was placed on the bottom. The bundle was sand packed and then sealed with bentonite up to the level of the next bundle installation. Three bundles were placed in each hole: at the bottom, midpoint, and just below the soil surface. Instrument bundles consisted of a thermocouple, redox probe, pneumatic piezometer and two 3.2 mm diameter tubes. The bundle was placed inside of 300 mm of 50mm diameter slotted screen. 25mm poly tubing was placed over the cables and attached to the screen with a watertight seal. After bundle installation, the tubing was extended to the EMS bank for installation in a weatherproof panel. These installations will allow measurement of temperature, ORP and hydraulic head below the EMS as well as provide the ability to obtain a water sample at the elevation of the installed bundle.

3.5.4 Sampling Events

Aug., 1998:	soil cores
Jan. 1, 1999:	water levels
June 3, 1999:	water levels, redox
Sept. 28, 1999:	water levels, redox, temperature, characterization of source
July 22, 1999:	water levels
Oct. 22, 1999:	water levels
Nov. 10, 1999:	water levels
Nov. 23, 1999:	water levels
Dec. 15, 1999:	detailed sampling, water levels
Feb. 17, 2000:	detailed sampling
March 15, 2000:	water levels, temperature
April 17, 2000:	water levels, redox, temperature
May 9, 2000:	water levels, redox, temperature
June 7, 2000:	water levels, redox, temperature
July 4, 2000:	water levels, redox, temperature
August 14, 2000:	water levels, redox, temperature
Sept. 22, 2000:	water levels, redox, temperature

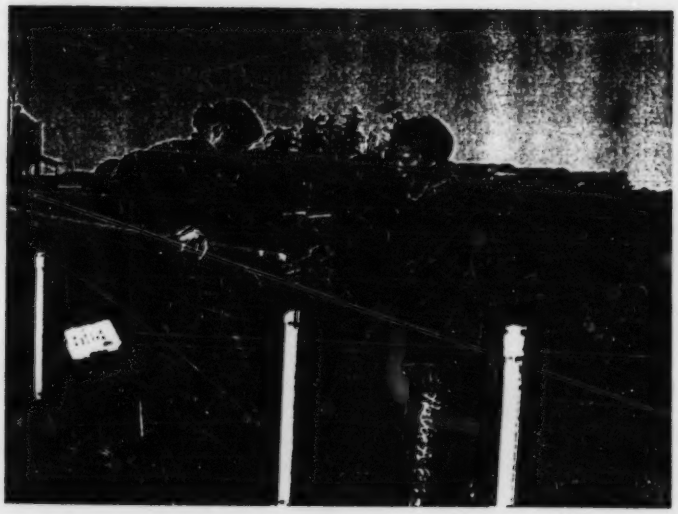

Figure 3.18 – Piezometer and source sampling at Site No. 9

Detailed sampling water sampling was completed at specific locations at this site on Dec. 15, 1999 and Feb. 17, 2000. Detailed sampling consisted of baling the piezometer and then inserting a field laboratory down the piezometer. Once readings had been taken, a water sample was extracted, filtered to 0.45μm, preserved and place in an insulated cooler. The installations chosen demonstrated the highest levels of nutrients and were thus chosen as to represent the center of the plume. All water samples from this sampling event were taken to the water chemistry laboratory of the Saskatchewan Research Council for analysis the day of sampling. It should be noted that the "plume" this site is within 50mm to 100mm thick sand lenses.

The EMS was emptied at the end of October, 1999, and at approximately the same time in 2000.

3.5.5 . Results

2M KCl extraction results indicate NH_4^+ seepage in the sand lens intercepting the side of the EMS (Figure 3.19). NO_3^- was found near the EMS in soils that experiences unsaturated conditions during periods following EMS emptying.

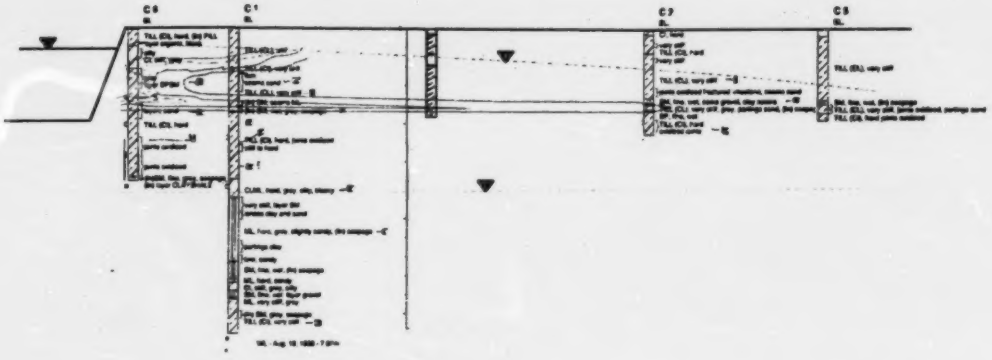

Figure 3.19– Site No 9 section showing seepage location, pressure head in the lower silt and sand deposit and the water table induced by seepage.

Water levels at the site are influence by the liquid level in the EMS as demonstrated in Figure 3.20.

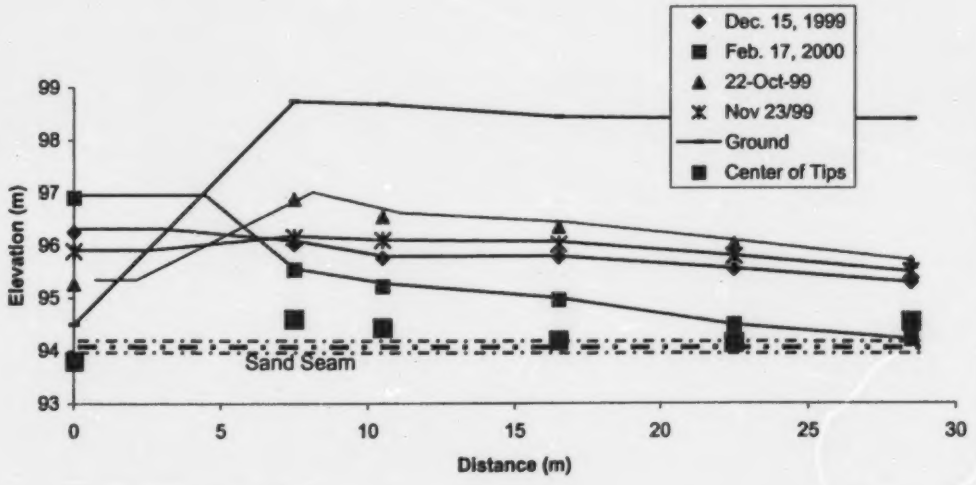

Figure 3.20 – Site No 9 water levels October 1999 to February 2000

Results of the detailed sampling revealed that the source chemistry was reflected in the sand lens to at least 23 meters from the storage (Figure 3.21). No background chemistry is known at this site but it is likely anion levels at the furthest location sampled are still elevated as a results of seepage in the lens being monitored.

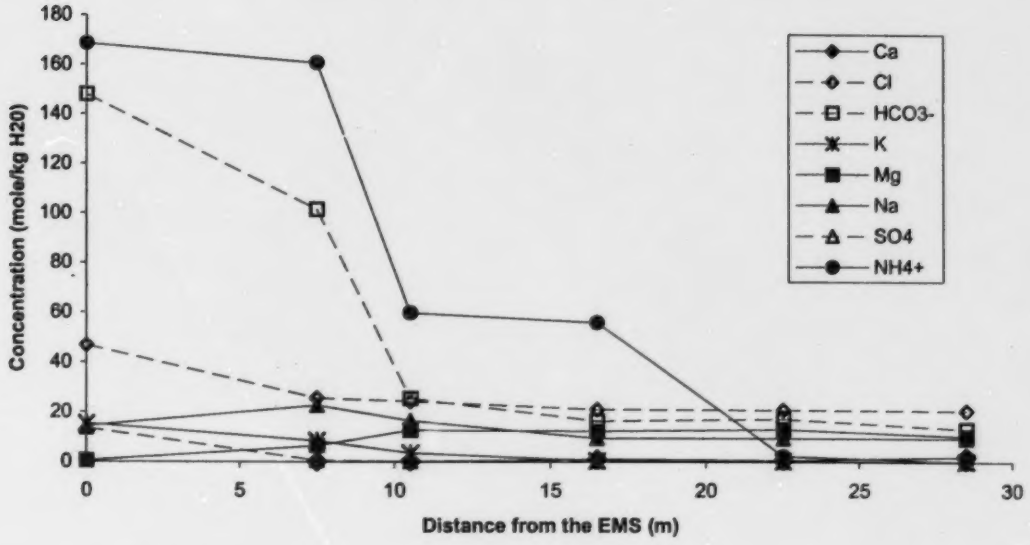

Figure 3.21 - Solution chemistry in sand lens experiencing seepage at Site No 9

3.6 Research Site No. 1

3.6.1 Site Description

Site 1 is located south of Saskatoon. The EMS at this site services a 250-sow farrow to finish hog barn. It was constructed in 1984 in stratified sands, silts and clays. No legal land location will be given as part of our access agreement with the owner.

3.6.2 Site Background

The top 100-m at this site consists of stratified silty clay drift. This is underlain by about 60-m of non-calcareous silt and clay of the Bearpaw Formation. The following 200 to 300-m are of the Lea Park Formation - Upper Colorado Group.

Test drilling at the site indicates 100 to 300 mm of topsoil followed by silts and sands to a depth of 5 to 7 meters. This was followed by layered soft sands, silts and clays overlaying stiff clay at depths of 5 to 10 meters below grade.

Water table elevations range from 1.5 to 3 m below ground surface.

3.6.3 Monitoring System Installation

On February 15 to 19, 1999, PFRA and the U of S installed monitor wells and obtained soil samples adjacent to the EMS (Figure 3.22). Piezometer nests were installed in a line running south from the EMS, which was determined to be the general direction of groundwater flow by previous studies (Fonstad and Maule, 1995). Soil cores were taken at each nest location in 60 mm x 750 mm brass liners, which were then sealed and stored between 2°C and 6°C Soil cores were extruded in PFRA's lab in Regina on March 8 to 10, 1999 and samples sent to the U of S Soil Science Laboratory for 2M KCl extractions for ammonium and nitrate. The

remaining soil was analyzed by PFRA for grain size, Atterberg Limits, density, specific gravity, water content and hydraulic conductivity.

On March 22, 1999, drilling was completed through the ice in the EMS. Drilling was accomplished with a rotary drill rig using a hollow stem auger and Shelby tubes for sampling. The rig was parked on the ice surface of the EMS and the hollow stem auger drilled down to the soil surface. Shelby tube samples were taken and the auger drilled down to the level of the sample. This procedure was repeated to a depth of 3 to 4 meters. Samples were placed in cold storage until extrusion was possible. The finished test hole was then cleaned out and an instrument bundle was placed on the bottom. The bundle was sand packed and then sealed with bentonite up to the level of the next bundle installation. Three bundles were placed in each hole: at the bottom, midpoint, and just below the soil surface. Instrument bundles consisted of a thermocouple, redox probe, pneumatic piezometer and two 3.18 mm diameter tubes. The bundle was placed inside of 300 mm of 50mm diameter slotted screen. 25mm poly tubing was placed over the cables and attached to the screen with a watertight seal. After bundle installation, the tubing was extended to the EMS bank for installation in a weatherproof panel. These installations allow measurement of temperature, ORP and hydraulic head below the EMS as well as provide the ability to obtain a water sample at the elevation of the installed bundle.

Gas samplers were installed on October 4, 2000. Stacked samplers were installed at five different locations. Sampling depths vary from 0.25 to 2.5 meters below ground surface.

ORP probes were added September 10, 2001 at four locations within the plume. Probe depths range from 1 to 11 meters below grade.

3.6.4 . Sampling Events

May 20, 1999:	Water levels, redox readings
June 23, 1999:	redox, pneumatic piezometers, temperature
July 20, 1999:	water levels
Sept. 3, 1999:	water levels
Oct. 1, 1999:	water levels, pneumatic piezometers, redox, temperature
Nov. 29, 1999:	water levels, pneumatic piezometers, redox, temperature
Feb.21, 2000:	detailed water sampling, redox, pneumatic piezometers
Summer, 2000:	water levels, pneumatic piezometers, redox, temperature
Sept. 26, 2000:	water levels, pneumatic piezometers, redox, temperature
Oct. 17, 2000:	water sampling, water levels

Detailed water analysis was conducted at this site on February 21, 2000. Water samples and in situ readings were taken from C15, C18, C21, C24, and C-29. C15 to C24 are the piezometer with the highest electrical conductivity at each nest location while C29 is the background piezometer installation.

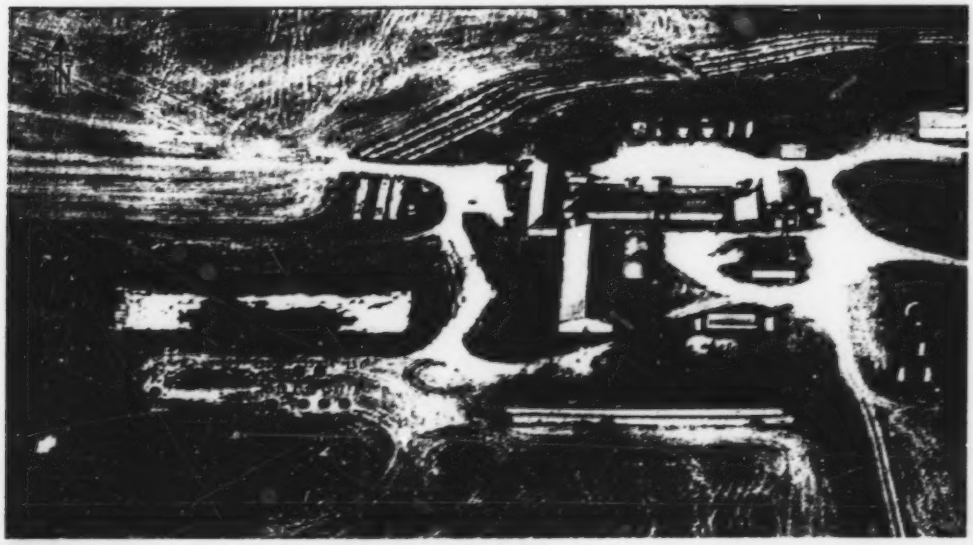

Figure 3.22 – Arial view of Research Site No. 1

3.6.5 . Results

Water levels at this site do not appear to be influenced by the liquid level in the storage (Figure 3.23). Figure 3.24 illustrates temperature profiles during mid January at the site. Temperatures remain relatively constant within the plume zone at 5 to 8 °C. Figure 3.25 illustrates the ORP conditions at three locations on the south side of the storage. All sites show distinct anaerobic (low Eh) conditions below the water table.

As groundwater passes beneath the storage it picks up relatively high levels of bicarbonate, ammonium, chloride and potassium (Figure 3.26). While chloride appears to follow standard advection dispersive movement, potassium and, to greater extent, ammonium levels drop sharply and reduce to low levels within 34 meter of the storage center line. Not as evident in Figure 3.26 due to the scale of the y-axis, is the significant increase in magnesium and calcium concentrations 22 and 53 meters respectively. This increase is due to displacement of these ions from soil exchange sites by the high level of monovalent cations in the seepage solution. This "hard water front" is commonly seen in studies of seawater intrusion into fresh water aquifers. It may be possible to use this hard water front as an early indicator of seepage from an EMS.

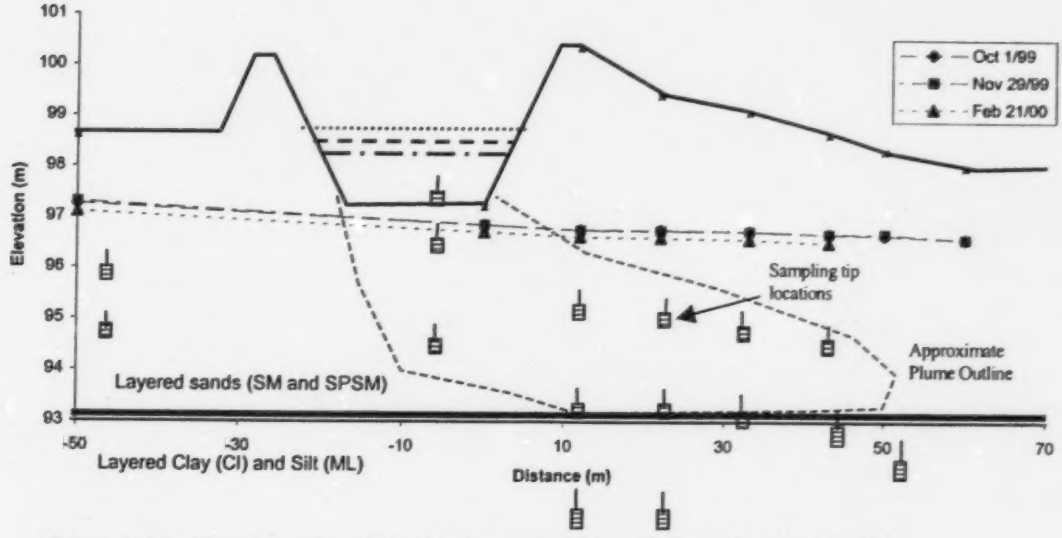

Figure 3.23 – Water levels at Site 1 between October 1999 and February 2000.

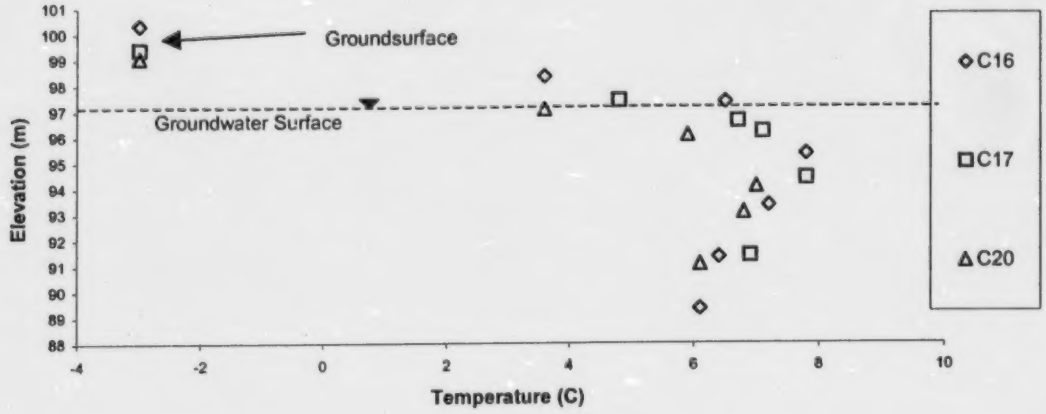

Figure 3.24 - Temperature Profiles at Site No 1 mid January

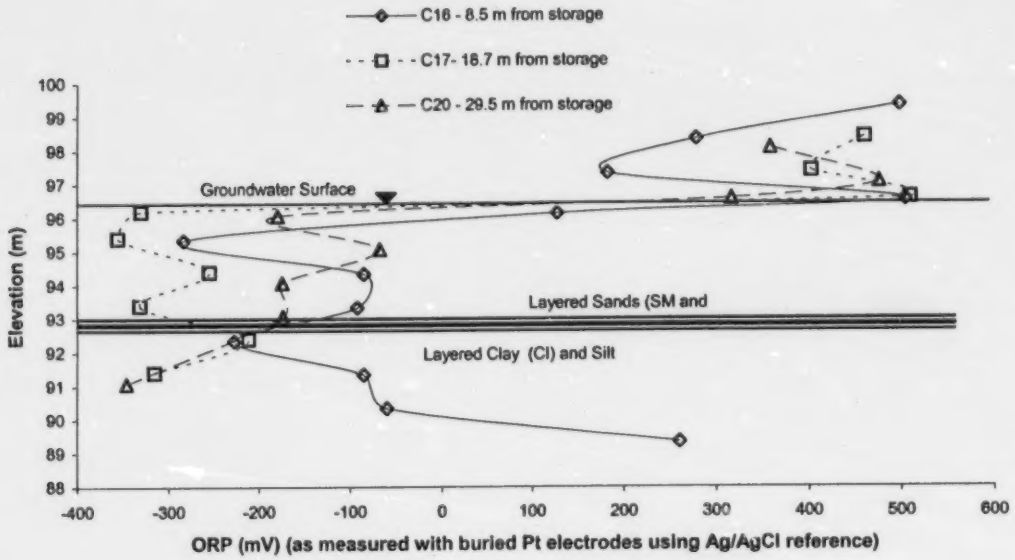
C16 - 8.5 m from storage
C17- 18.7 m from storage
C20 - 29.5 m from storage
Groundwater Surface
Layered Sands (SM and
Layered Clay (Cl) and Silt
Elevation (m)
ORP (mV) (as measured with buried Pt electrodes using Ag/AgCl reference)

Figure 3.25 – ORP readings at three locations at Site No 1

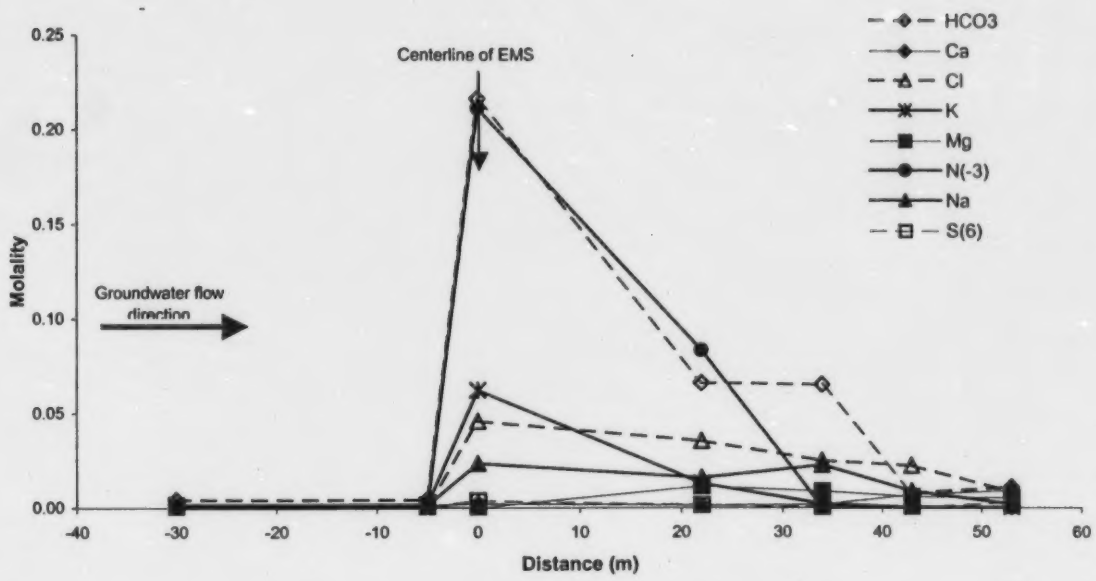

Figure 3.26 – Ion concentrations within the plume at Site No 1

3.7 Source Chemistry

Several EMS were sampled over the course of this project. No published reference could be found giving examples of EMS chemistry of the fluid portion within the EMS. EMS samples commonly undergo acid digestion prior to analysis in an attempt to determine total ion concentrations within the sample. Since the solid fraction of the solution does not transport it was necessary to obtain representative samples with depth, filter them to 0.45μm and then conduct water analysis on the sample. Sampling was achieved using and aluminum fishing boat. Each EMS was sampled as deep as possible using a specially constructed sampler with valves activated when the sampler was at the required depth. At the same time, D.O., pH, EC and temperature readings were taken with depth. Data from Site No 1 is shown in Figure 3.27.

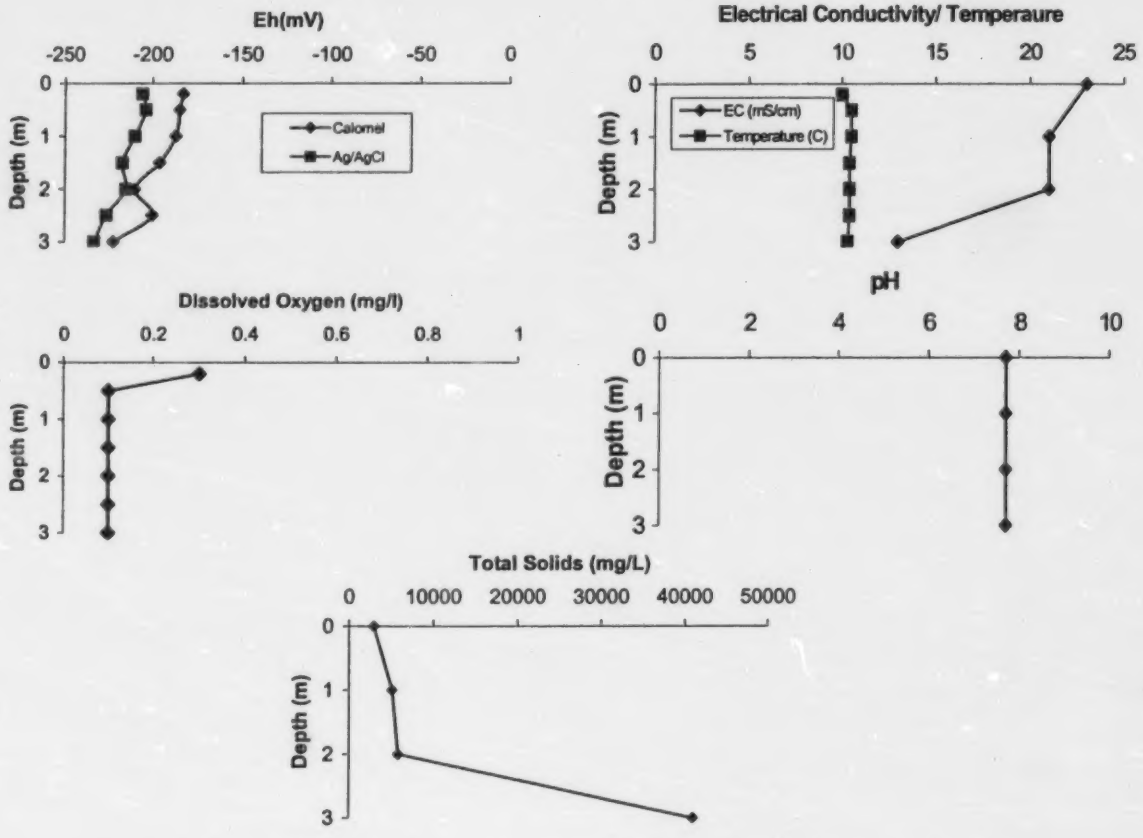

Figure 3.27 – Eh, EC, DO, pH, and Total Solids versus depth at Site No 1

The chemistry of the "pore fluid" within EMS was similar for all the storages sampled. The most abundant ions, by far, are bicarbonate (HCO_3^-) and ammonium (NH_4^+). The next most abundant ions where found to be approximately one-third the activity or one-quarter the molality of bicarbonate and ammonium and included potassium (K^+), chloride (Cl^-) and, often, sodium (Na^+). All other ions appear to play a minor role. Commonly, levels of sulphate (SO_4^{-2}), calcium (Ca^{+2}) and magnesium (Mg^{+2}) are much lower in the EMS "pore fluid" than in the soil pore fluid. Figures 3.28 and 3.29 give selected data in terms of ion concentration and molality respectively.

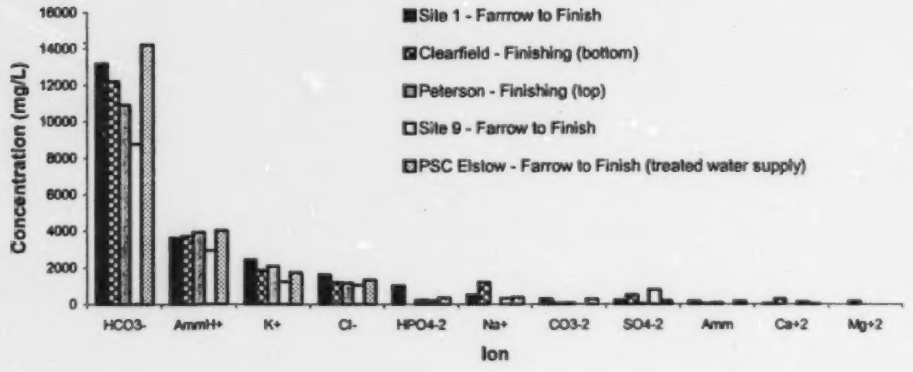

Figure 3.28 – Typical source chemistry (concentration in mg/L)

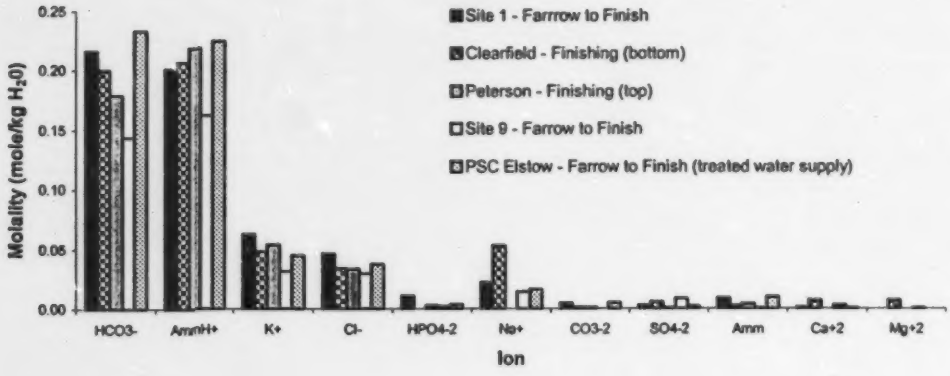

Figure 3.29 – Typical source chemistry (concentration in mole/kg H_20)

3.8 Column Study

Include in the study of potential EMS seepage was a column study to attempt to both characterize the source (manure) above soil liners and to test several subsoils under manure heads typically found in Saskatchewan EMS. Columns were constructed and placed in a lab at the Prairie Agricultural Machinery Institute (PAMI) in Humboldt, Saskatchewan. Columns were fashioned after those used by both Barrington et al. (1987) and Fonstad (1996) Columns were constructed of 300 mm diameter PVC DR35 pipe that was placed vertically to form a 4-meter column. The bottom 1 meter of the column was used to compact soil for hydraulic conductivity testing and seepage analysis while the top 3 meters was used for settling studies (by PAMI), EMS source characterization and as the source of manure for the seepage study. Figure 3.30 gives a diagram of a typical column showing the location of the various sampling valves, manometers and Eh probe installations. Six 50 mm PVC pipes and valves were installed for manure sampling within the top 3 meters and four 19 mm PVC pipes and valves were installed within the soil in the lower 1-meter of the column. Each pipe was installed to the center of the column. All 19 mm diameter pipes were covered with soil filter cloth to ensure no plugging. The 19 mm pipes allowed seepage into the end within the soil with the remainder of the pipe acting as a reservoir for sample volume. Each 19mm pipe also had a manometer tube plumbed into the pipe prior to the valve to measure pressure head. Eh or Redox probes were installed at each valve location to attempt to measure redox conditions and to verify the usefulness of the redox probes. A 19 mm PVC pipe and valve was placed in a gravel layer below the soil column for effluent collection. The top 3 meters of the column was coupled to the lower meter to allow for dismantling of the column later and sectioning of the soils for sampling.

Columns were constructed in early 1999 and the soils compacted into the columns on March 15, 1999. Soils used were from various research sites with soils from the Big Sky Clearfield site and Research Site No.1 being place in Columns No. 1 and No. 2 respectively. The soils were compacted wet of optimum moisture content to compaction levels less than optimum with a simulated Proctor hammer. Soils in Columns No.1 and No.2 were compacted at 3.2% and 7.8% above optimum respectively to dry densities of 95% and 92% of maximum

Standard Proctor. Each column was tested with water for initial hydraulic conductivity. Column No.2 was filled with manure on April 5, 1999 and Column No. 1 filled on April 8, 1999. After manure filling each column was monitored for liquid level, manometer levels, volume of exfiltrate with time, and Eh (redox) readings. After exfiltrate measurement the exfiltrate was replaced into the top of the column to maintain head.

Periodically water samples were taken from each 19-mm pipe and from the exfiltrate container. Initially water samples were taken to the laboratory at the Department of Agricultural and Bioresource Engineering at the University of Saskatchewan for analysis of EC, ammonium, nitrate, chloride and potassium by ion selective electrode. Final samples, and some intermediate samples, were analyzed using a Dionex Ion Chromatograph in the College of Geologic Sciences at the University of Saskatchewan.

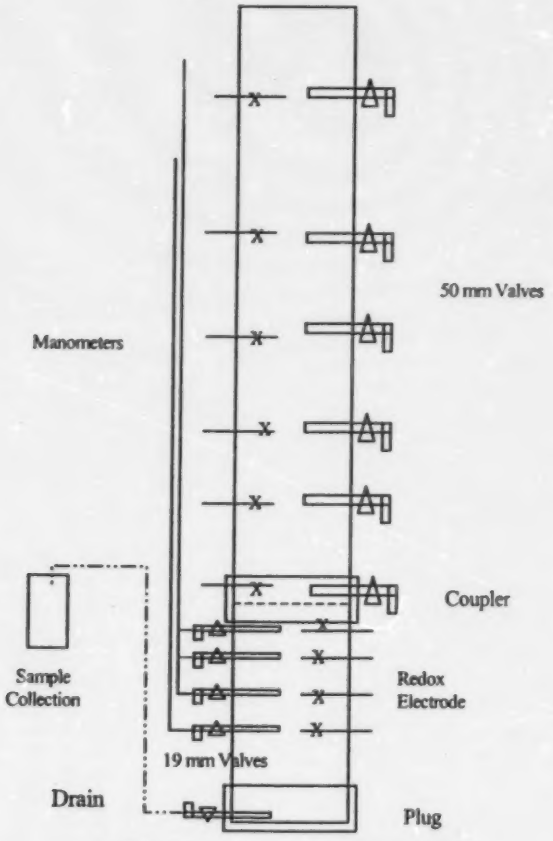

Figure 3.30 – Test column setup

On August 18, 1999 all columns were dismantled by first draining off the manure in the top 3 meters, taking the top 3 meters of the column off and then wrapping the bottom 1 meter of column containing the soil with plastic for transport to the U of S. Columns were then place in a walk-in freezer for storage and stored at –30 °C until April 2000.

Columns were dissected in late April 2000. Column No. 1 was dissected on April 27 and Column No. 2 on April 28, 2000. The approximately 850 mm long soil columns were sectioned into maximum 50mm layers. Each layer was split and one-half the sample was sent to the Soil Science laboratory at the University of Saskatchewan for determination of ions on the exchange sites and ions in solution.

Hydraulic conductivities of both columns reduced to below $1x10^{-7}$ cm/s shortly after ponding of the manure. Column No 1 did not experience ion breakthrough while 3.6 pore volumes passed through Column No 2 resulting in breakthrough of several ions. Results are plotted in Figure 3.31.

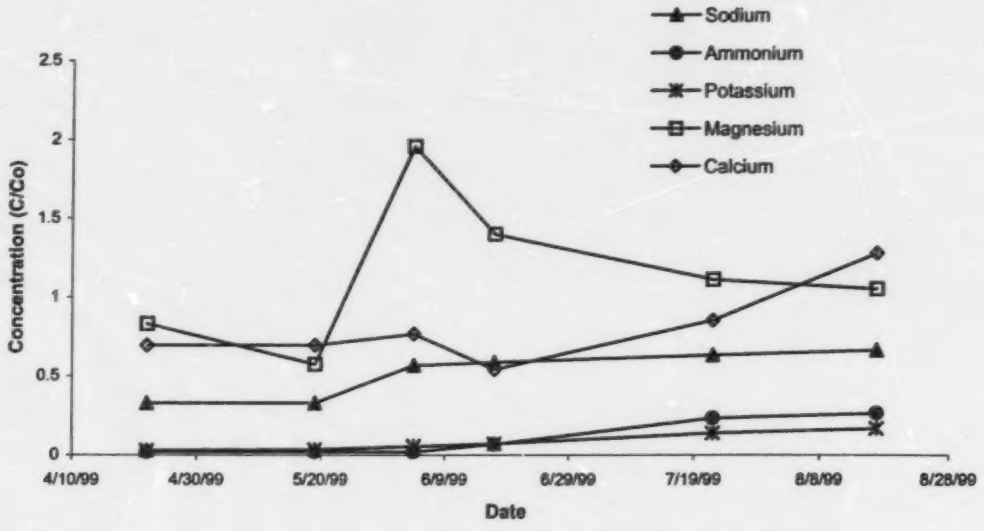

Figure 3.31 – Breakthrough curves for major cations - Column No 2

By analyzing the change in cation concentration on the exchange we can see the impact ion exchange has on the transport of ammonium and potassium. Figure 3.32 shows the change in

ion concentration on soil exchange sites versus depth for the clay till material from the Clearfield Feeder Unit site in Column No 1. Sodium appears to be relatively uninvolved in any exchange reactions while ammonium and potassium appear to be exchanging for calcium and, to a greater extent, magnesium. Some magnesium and calcium will likely precipitate as gypsum and calcite but there is evidence that a large portion is displaced down the column. Figure 3.33 shows the change in ion concentration on soil exchange sites versus depth for the sandy material from Site No 1 in Column No 2. Again sodium appears to play a minor role in the ion exchange process. Ammonium and potassium displaced large amounts of calcium and magnesium from the exchange sites. While calcium was simply displace down the column, magnesium has been washed from the column. Looking again at Figure 3.31 and noting the peak of magnesium coming out of the column near mid June confirm this. Figure 3.34 shows the pore water ion concentrations from 2:1 saturated paste extraction from the soil samples. There are several things to note from this figure:

1.0 Sodium appears to be advancing at the same rate as chloride and bicarbonate.

2.0 Calcium and magnesium removed from soil exchange sites are present near the advancing front form the afore-mentioned hard water front.

3.0 The ammonium front is relatively flat nearly resembling plug flow.

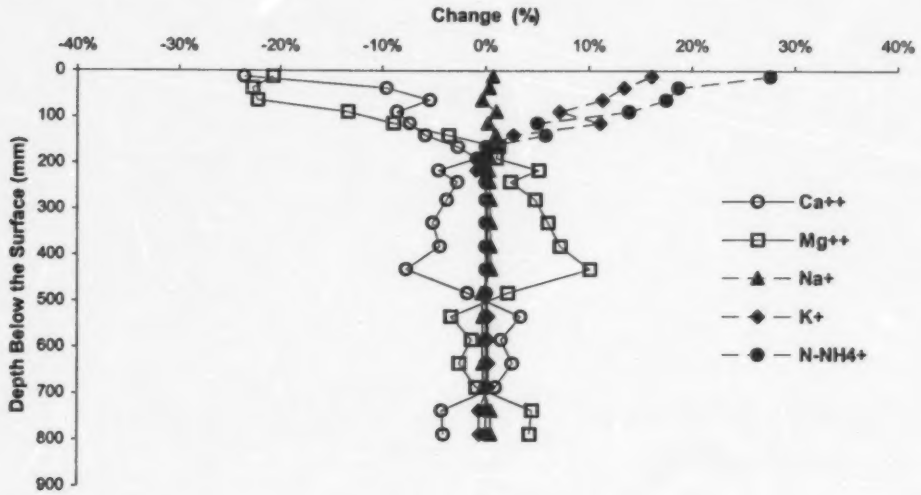

Figure 3.32 - Change in ion concentration on soil exchange sites versus depth - Column No 1

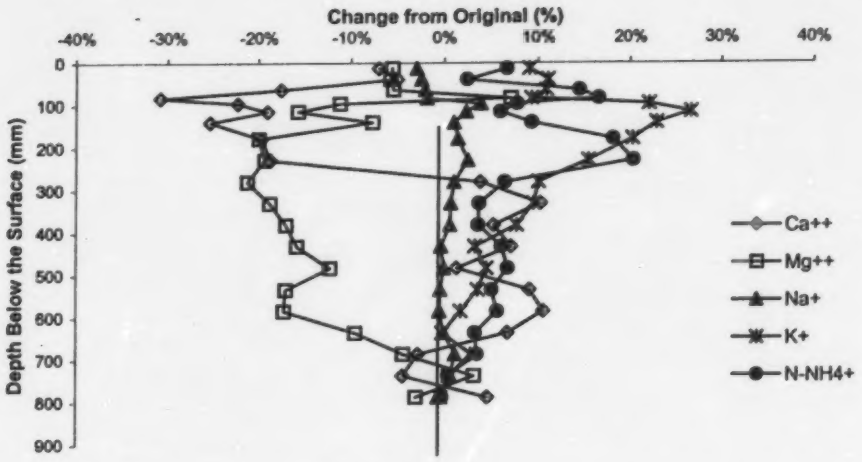

Figure 3.33 - Change in ion concentration on soil exchange sites versus depth - Column No 2

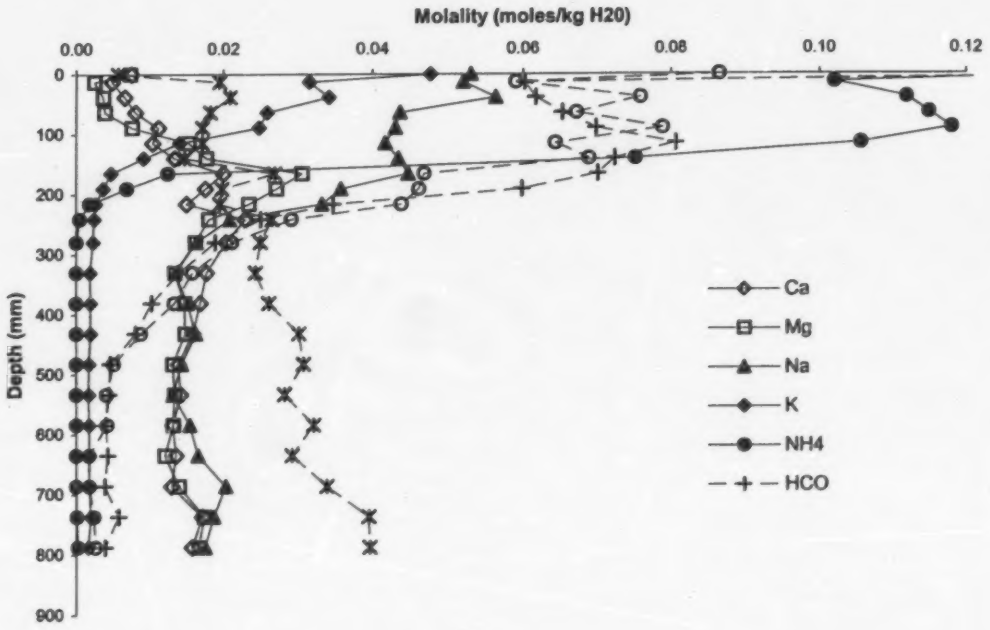

Figure 3.34 – Pore water chemistry ion profiles in Column No 1 at the end of testing

Data of ion concentration in solution and on exchange sites were plotted according to the Langmuir isotherm theory. While results for calcium (Figure 3.35), magnesium (Figure 3.36), sodium (Figure 3.37), and potassium (Figure 3.38) provide reasonably good fits to the Langmuir theory, ammonium data resulted in a simply scatter of data points. Either ammonium does not fit this theory or there is a lack of data points. Data from Column No 2 was then plotted according to a method proposed by Shackelford (1995) where by the cumulative mass ratio (CMR) is plotted versus pore volumes (Figure 3.39). Breakthrough data plotted in this method will for a 1:1 line when breakthrough has occurred and the intercept of this line with the x-axis (pore volumes) indicates directly the retardation factor (R). Results of this exercise indicated that ammonium was initially retarded by a factor of approximately 3 but this reduced to no retardation as ion concentrations increased. Through curve fitting, it was determined that the retardation of ammonium decrease at a rate approximately equal to $R=3\ [NH_4]^{-0.15}$ where ammonium concentration is in mg/L. Using this relation for retardation of ammonium, no retardation of chloride and the Langmuir results for potassium, calculated profiles were plotted versus actual measured ion pore water concentrations. These are given in Figure 3.40.

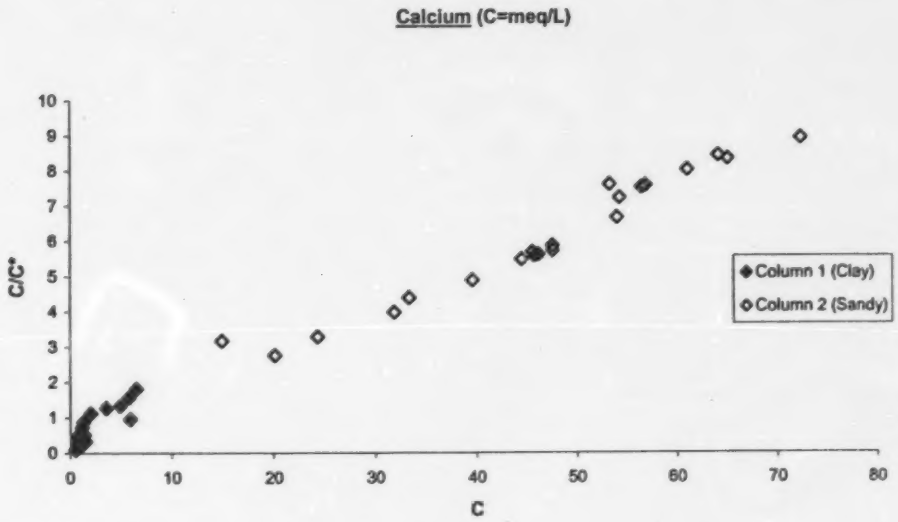

Figure 3.35 – Langmuir isotherm plot for calcium

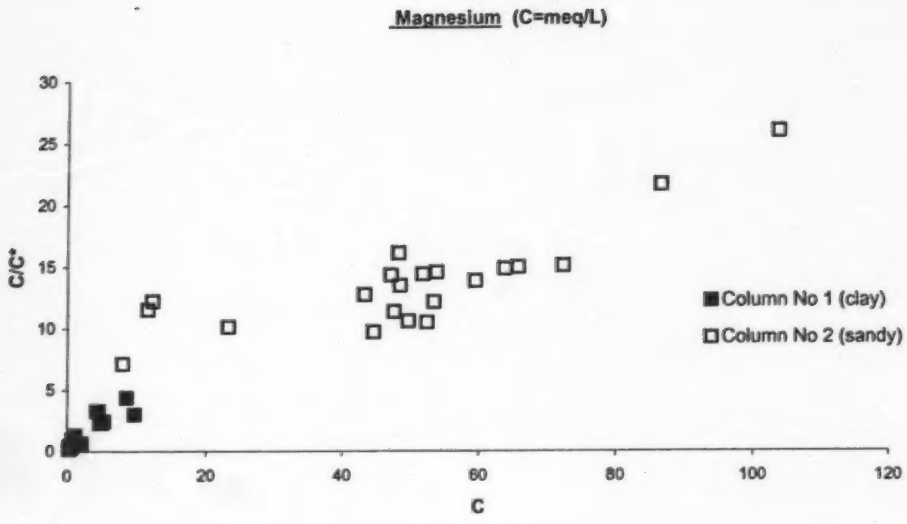

Figure 3.36 – Langmuir isotherm plot for magnesium

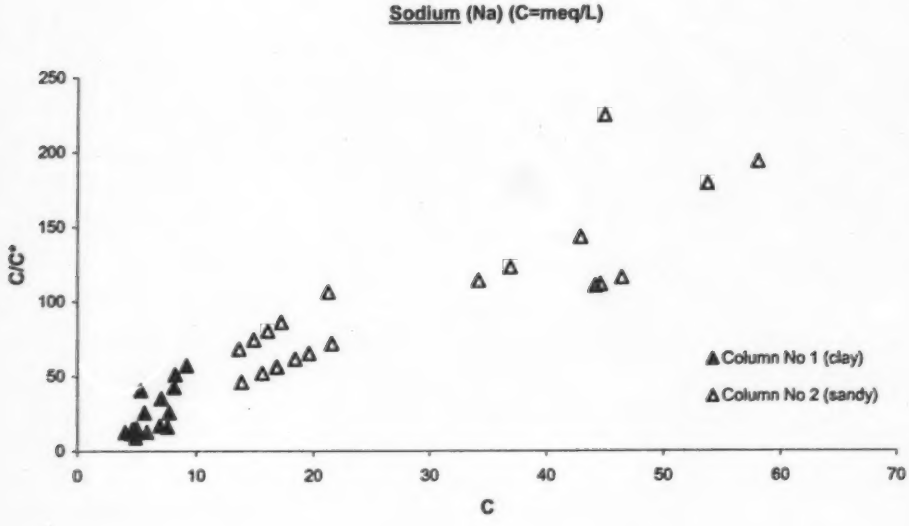

Figure 3.37 – Langmuir isotherm plot for sodium

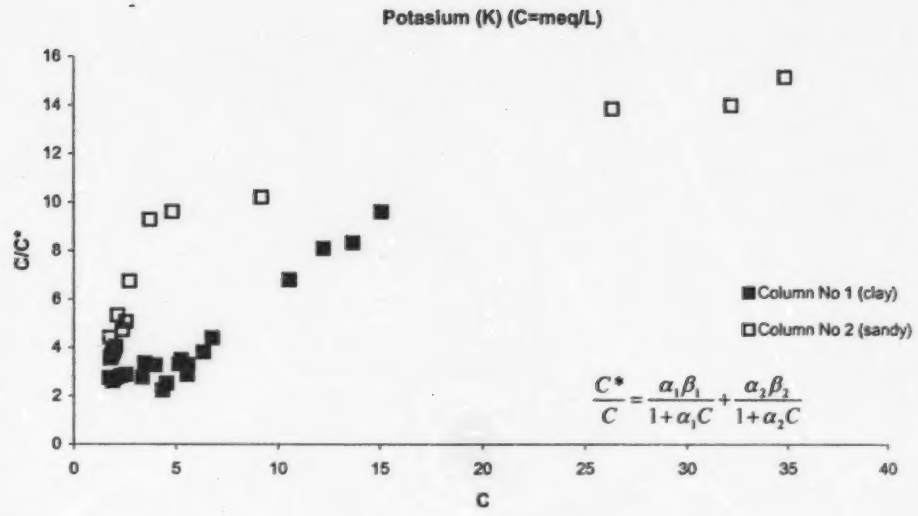

Figure 3.38 – Langmuir isotherm plot for potassium

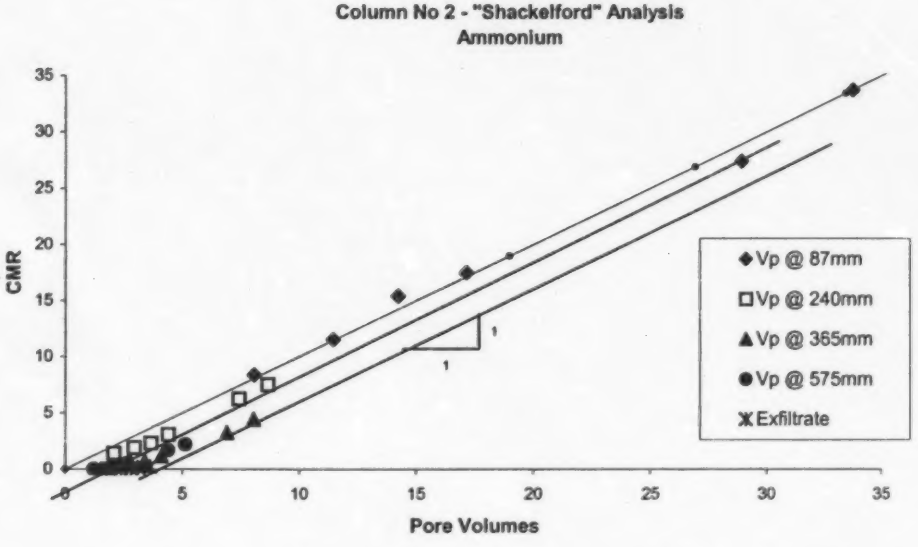

Figure 3.39 – "Shackelford" analysis of Column No 2 breakthrough data

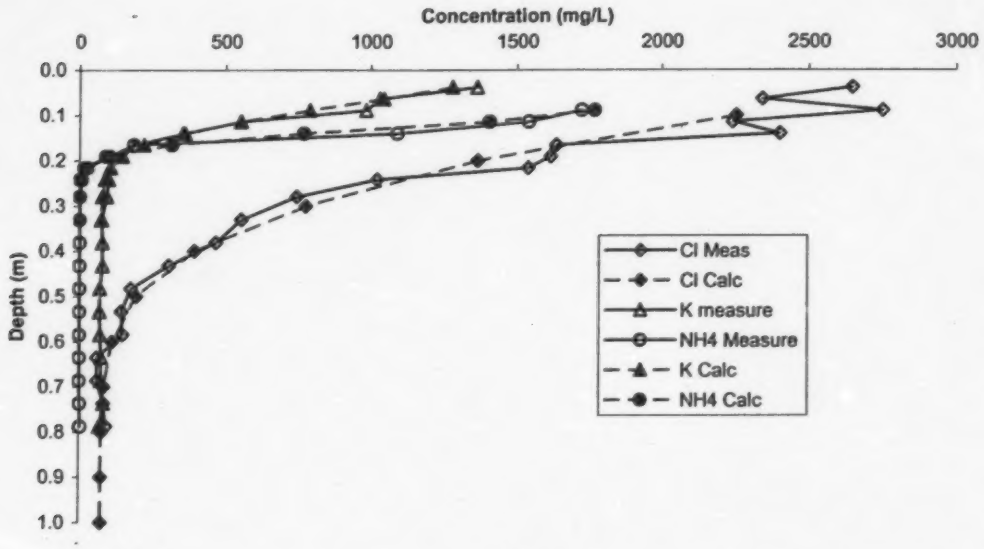

Figure 3.40 – Comparison of measure versus calculated transport of potassium, ammonium and chloride for Column No 1

4.0 Summary of Results

The chemistry of the "pore fluid" within EMS was similar for all the storages sampled. The most abundant ions, by far, are bicarbonate (HCO_3^-) and ammonium (NH_4^+). The next most abundant ions where found to be approximately one-third the activity or one-quarter the molality of bicarbonate and ammonium and included potassium (K^+), chloride (Cl^-) and, often, sodium (Na^+). All other ions appear to play a minor role. Commonly, levels of sulphate (SO_4^{-2}), calcium (Ca^{+2}) and magnesium (Mg^{+2}) are much lower in the EMS "pore fluid" than in the soil pore fluid.

Of the three EMS with systems installed at the new sites, only one has been filled to capacity since the installation of the monitoring system. This storage is the EMS at the Clearfield Feeder Unit. There have been several significant findings at this site to date:

1. Groundwater mounding occurred almost simultaneous to filling of the EMS. This means that the water table directly adjacent to high water level in the EMS was similar to the high water level. The water mound gradually decreased with distance and appears to meet the site water table at a distance of approximately 60 meters from the storage. This mound did not dissipate when the EMS was emptied. This means that groundwater discharge conditions exist within the second cell and possibly the first cell during periods when the cells are not full.
2. Seepage has occurred significantly more on the sides than on the base of the storage. Electrical conductivity values of water samples indicate seepage to depths of approximately 0.6 meters on the sides of the storage and 0.1 meters on the base of the storage within the first three years of operation.
3. Liner breaching as a result of damage to the liner has been indicated in the monitoring system in the first cell. Resulting seepage has infiltrated any available preferential flow paths adjacent to the liner and will continue to be monitored even after the liner damage has been repaired. The significance of this finding is that one of at least two things should happen. Either, agitation equipment needs to be altered with shields and flotation tires or agitation pads and access ramps should be installed at all EMS.

Investigation of the older sites has indicated that chemistry of the "pore fluid" of the source has a significant affect on the formation and transport of a plume. Significant findings from investigation of the plumes at these sites include:

1. Vertical flow of solutes seeping from an EMS can be assisted by gravity as the higher TDS seepage water will "settle" do the higher density.
2. The elevated levels of monovalent cations displace calcium and, to a greater extent, magnesium on the soil exchange sites. These displaced ions form a "hard water" front at the leading edge of a plume. Magnesium and calcium levels can exceed 100 and 10 times the normal levels respectively. Detection of this "hard water" may offer the ability for early detection of seepage plumes
3. Bicarbonate (HCO_3^-), chloride (Cl^-) and sodium (Na^+) follow standard advection dispersion transport with no noted retardation.
4. Transport of ammonium (NH_4^+) and potassium (K^+) is somewhat retarded. The ability of the soil to retard ammonium and potassium appears to be depleted exponentially as the pore water concentration increases. The significance of this is that as concentration increases, retardation decreases until a level is reach where transport is unretarded advective dispersive movement.
5. The above-mentioned process produces a relatively flat concentration front of ions advancing through the soil. This front nearly resembles "plug" flow with a velocity at C/Co= 0.5 of 0.65 and 0.5 the velocity of chloride for ammonium and potassium respectively. The significant difference from chloride movement being that the when the ammonium front does pass, the concentration will increase relatively quickly from background to very nearly the source concentration.

A question to arise from these studies has been in regards to the fate of the ammonium and potassium that finally resides on the exchange sites of the soil surrounding an EMS. Initial siting, operational procedures and decommissioning strategies all need to consider the long-term fate of these ions. By far the easiest solution still remains to place effort on the original siting of these facilities and proper engineering of soil liners and interceptor drain systems.

5.0 Changes From Original Proposal

5.1 System design

The original design proposal consisted of a large lysimeter installation under the EMS liner. This involved placing a gravel layer under the liner containing drain lines leading to a collection manhole, similar to systems installed in sites in Saskatchewan (Maule and Fonstad, 2000) and Minnesota (Swanberg 1997; Ruhl 1999). Review of this system indicated that:

- the gravel layer would likely create a capillary break, reducing actual seepage
- there was reported difficulties with trench subsidence and seepage, and
- representative water quality samples would be very difficult. There would be more than 450 L of stagnant water that would have to be pumped prior to sampling and water flowing into the wet well would be in contact with air causing temperature change and oxygen infiltration.

A system involving electronic instruments and access tubes accessible from a walkway was then considered. Investigation of affordable instruments fitting durability requirements revealed that moisture content variations between 90% and 100% saturation might not be detectable. Since 90 to 100% saturation would be the range of moisture contents likely to be encountered, this was unacceptable. Further, there was significant concern that the dynamic nature of the EMS liquid level would cause ice damage to the walkway, access tubes and instrument cables. At this point, several EMS design conditions were reviewed and a monitoring system for saturated conditions was designed through consultation with experts in the field and the research team. The final design involves installation of 0.30 to 0.50 meter long piezometer tips at various levels in the bottom, on the side, at high water level and at the berm centerline of each cell of an EMS. Each piezometer tip has a pneumatic piezometer or standpipe for head, a thermocouple for temperature, a redox probe for oxidation-reduction potential, and two 3.2 mm diameter suction tubes for water sampling.

The number of piezometers surrounding the EMS's at the newly constructed facilities has also been increased from that proposed in the original design. This was done for the same reason as the other changes in the system: to achieve more thorough, and therefore useful, results. Monitoring of surrounding piezometers allows closer examination of any changes in hydrology that may be occurring due to the presence of the storages. This information will allow analysis of the hydraulic gradients affecting transport of contaminants in the groundwater.

This system used achieves the minimum cost requirement of industry cooperators, involving approximately $12 000 to $15 000 worth of materials, while delivering maximum results. However, the system did involve substantially more effort on the part of the U of S and PFRA for installation and sampling.

The monitoring system at an old site, Site 1, was also made more thorough. Shallow, narrow piezometers were installed at five locations for the purpose of gas sampling. These samplers were installed because of the noticeable lack of dissolved oxygen in the water at this site, and will allow monitoring of the movement of O_2, N_2, and CO_2. In the fall of 2001 the research team installed redox probes from the surface down to at least 8 to 11 meters to attempt to confirm the presence of aerobic conditions in the vadose zone and anaerobic conditions within the saturated zone at the site.

5.2 Number of Sites

The original proposal indicated the establishment of the original monitoring system design in nine newly constructed storages. Due to the higher costs of installation and sampling of the final system design over that originally planned, the number of sites involved in this project was decreased. Two established single cell EMS and three newly constructed two cell EMS have systems installed.

5.3 . Installation

Manholes for the final system design were originally placed at a depth of approximately 3m to allow for water to be suctioned from Locations 1 and 2. This required a trench to be dug into the liner at the same depth to allow the instrumentation to come into the bottom of the manhole. Due to the difficulty of excavation of such a trench and the concern of seepage, it was decided that the manholes need only be 1.5m in depth. Required trenches were able to be excavated with a small trencher instead of a backhoe. As a result, the trenches are both narrower and shallower (only 0.5m below the liner for a short distance). The smaller trenches allowed for better sealing by bedding the tubing in bentonite powder.

6.0 Future Work

Funding is currently in place to sample these sites until the summer of 2006.

Existing new data will be used to produce and modify contaminant transport models.

Precise determination of the insitu denitrification rate would help to accurately estimate plume growth and the potential for nitrate transport.

In order to get the full picture of the chemical reactions and transport that is occurring beneath and beside these storages, it may be useful to qualify and quantify the microbial population.

Mr. Steve Gibbard is completing a M.Sc. thesis (Department of Agricultural and Bioresource Engineering, December 2002) on the automated measurement of temperature and oxidation-reduction potential (ORP) for the systems installed at the new sites.

Mr. Terry Fonstad is completing a Ph.D. thesis (Department of Civil Engineering, August 2002) on determination of source chemistry, transport mechanisms, transport coefficient determination and geochemical modeling using the information from one of the older sites and a large-scale laboratory column study.

7.0 PROJECT DEVELOPED MATERIALS

Several presentations of the results have been shared with stakeholders, researchers and technical groups. The following paper or poster presentations have been presented:

Fonstad, T.A, Maule, C.P., Ingram, L.J., Meier, D.E., Gibbard, S., Filson, H., Donahue, R. and Barbour, S.L., 2001. *Manure Seepage Plume Characterization: Results of a Detailed Study of a Manure Seepage Plume in a Sandy Soil in Saskatchewan.* In the Proceedings of the International Symposium: Addressing Animal Production and Environmental Issues. October 3-5, 2001, Sheraton Imperial, Research Triangle Park, Raleigh, North Carolina. P:672-675

Fonstad, T.A., Ingram, L.J., Meier, D.E., Gibbard, S., and Filson, H., 2001. *Initial Results of a Long-term Monitoring Program for Earthen Manure Storages in Saskatchewan.* In the Proceedings of the International Symposium: Addressing Animal Production and Environmental Issues. October 3-5, 2001, Sheraton Imperial, Research Triangle Park, Raleigh, North Carolina. P:624-629

Gibbard, S., Fonstad, T.A., Filson, H. and Ingram, L. 2001. Insitu Measurement of Oxidation-Reduction Potential Beneath Earthen Waste Storage Facilities. In "Preferential Flow – Water Movement and Chemical Transport in the Environment" Proceedings of the 2nd International Symposium. Honolulu, Hawaii, January 3-5, 2001. P:253-256.

Fonstad, T.A., 2000. Ion Exchange During Plume Development from an Earthen Manure Storage. Presented to University of Saskatchewan Civil Engineering Seminar Series, April 20, 2000. Saskatoon, Saskatchewan.